

Technological Advancement in Agro-forestry systems:

Strategy for Climate Smart Agricultural Technologies in SAARC Region



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**Technological advancement in agro-forestry systems:
Strategy for climate smart agricultural technologies in
SAARC Region**

Edited by
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December 2015



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Foreword

The presence of trees in backyard and within the agriculture field is unique in the farms in South Asia. Agroforestry has not only displayed the inevitable association between men and forest, but also truly helped to sustain farming systems in formidable conditions in the region. It also provides a harmonious balance between food production and environmental protection. In this context, soil and water conservation is an important strategy for sustainable crop production and environmental conservation. Assortment of agroforestry systems has evolved in response to pressure of population on land, technological options and market changes.



Traditional knowledge on integration of trees in the farm is so rich in the SAARC Region. All the eight SAARC Member States cover wide range of agro ecological zones, and people have been practicing trees in farm for generations.

Agroforestry systems promotes increased engagement of people in forestry management through participatory forestry management strategies, the role of people in developing and applying REDD+ mechanisms has become fundamental. In view of the dynamic socio-ecological interaction and benefits offered by agroforestry, it can be a basis for evolving climate smart agricultural technologies that is able to fulfill the social, economic and environmental benefits for land users at all levels. Agro-forestry is emerging as an enduring technology with ability to help socio-ecological systems develop resilience in the face of changing weather patterns.

When SAC initiated the program on “Technological advancement in agro-forestry systems: Strategy for Climate Smart Agriculture technologies in SAARC Countries”, it was overwhelming to see the support of Central Agroforestry Research Institute (CAFRI), Indian Council for Agriculture Research (ICAR), and World Agroforestry Centre-South Asia Office (WAC).

This book titled “Technological advancement in agro-forestry systems: Strategy for Climate Smart Agriculture technologies in SAARC Countries” is a comprehensive compilation of agroforestry information from 8 SAARC Countries. I would like to take this opportunity to express my sincere appreciation to Dr. Tayan Raj Gurung, Senior Program Specialist (NRM), SAARC Agriculture Centre and Mr. Karma Jigme Temphe, PFM Specialist, SAARC Forestry Centre who tirelessly worked through to put together the manuscript. I am confident that this compilation will facilitate further research and development in agroforestry in SAARC Region.

Dr. S. M. Bokhtiar

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Executive Summary

The integration of forest ecosystems into agriculture and social landscape is ingrained into the socio-ecological fabrics of South Asian farming community over centuries. It has not only displayed the inevitable association between men and forest, but also helped to sustain farming systems in formidable conditions in the region. The presence of trees in backyard and within the agriculture field is unique in the farms in South Asia. Agro-forestry is referred as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (ICRAF 1996, FAO, 2008). The management of complex agroforestry systems is largely dependent on the optimization of both ecological and social processes (Boni et al., 2004). Among the priority areas to consider in the practice of agroforestry is the harmonious balance between food production and environmental protection. In this context, soil and water conservation is an important strategy for sustainable crop production and environmental conservation. According to Dennis Garrity (1993), assortment of agroforestry systems has evolved in response to pressure of population on land, technological options and market changes.

Traditional knowledge on integration of trees in the farm is extensive in the SAARC Region. All the eight SAARC Member States cover wide range of agro ecological zones, and people have been practicing growing trees in farm for generations. Agro-forestry is therefore seen as a means of not only improving people's livelihoods through the supply of fruits, timber, fodder and fertilizer and therefore higher incomes, but also in stabilizing erosion, replenishing soils, storing carbon and enhancing on-farm biodiversity. In the present day context, contribution of agroforestry to the mitigation of climate change (through carbon sequestration) is of particular relevance at present as countries attempt to negotiate a mechanism for reducing emissions from deforestation and forest degradation (REDD+).

With the increased engagement of people in forestry management through participatory forestry management strategies, the role of people in developing and applying REDD+ mechanisms has become fundamental. In view of the dynamic socio-ecological interactions and benefits offered by agroforestry, it can be a basis for evolving climate smart agricultural technologies that is able to fulfill the social, economic and environmental benefits for land users at all levels. Agro-forestry is emerging as an enduring technology with ability to help socio-ecological systems develop resilience in the face of changing weather patterns.

In view of the evolution of agro-forestry systems, SAARC Agriculture Centre (SAC) and SAARC Forestry Centre (SFC) initiated a SAARC Regional

consultation to document the technological advancement in agro-forestry practices and assess its relevance as climate smart technologies. The specific objectives of the initiative were as follows:

- To document the innovative agroforestry practices under the influence of changes (climate, socio-economic, governance) in SAARC Countries
- To assess the productive and environmental functions of trees in agriculture landscape and its contribution to food security and poverty alleviation
- To identify emerging issues and propose strategies to develop agroforestry

This compilation is organized in ten chapters. The first chapter is the synthesis of the country papers and provide brief descriptions of agroforestry scenario in respective countries. The country papers as received from the national focal points are included in Chapter 2 to 9 in alphabetical order. The final chapter (10) presents the issues and recommendations drawn from the regional consultation meeting. Some of the pertinent issues raised are as follows:

- Absence of policy specific on agroforestry in many Member States
- Limited awareness about agroforestry
- Shortage of extension personals in the field of agroforestry
- Unorganized structure of agroforestry institutions and agriculture departments
- Poor technology dissemination and adoption
- Need for network on SAARC agroforestry for technology dissemination

The consultation meeting also made some recommendations related to policy, research and extension.

1. Policy

- Formulation of Agroforestry Policy/Framework/Guidelines for all SAARC countries

2. Research

- Complete inventory of existing AFS in all the SAARC countries (D&D Analysis)
- Identification of suitable climate smart agroforestry practices for different SAARC countries.
- SAARC regional coordinated project on AF in line with AICRP on Agroforestry in India
- Agroforestry intervention for watershed management (water harvesting ,storage, application and management, and participatory watershed management approach)
- Research on fodder species and livestock that can be integrated into agroforestry system
- Energy Smart Agroforestry (Biofuel – Jatropha, Pongamia, Madhuca, Simaruba, and bioenergy- Fuelwood, Gasifiers)

3. Extension and Training

- Training of extension in agroforestry and AF based watershed management
- Technology dissemination through field visits, exhibitions, and on farm trials
- Organize mass media: radio talks, Kisan call center, leaflets and news papers
- Training on D&D analysis
- Methodology to quantify Ecosystem services
- Training on conservation agriculture with trees, integration of trees and their management in agriculture, and biofuels-bioenergy
- Technology dissemination and adoption of smart and successful agroforestry technologies
- Establish network and website creation like SAAN (South Asia Agroforestry Network)

It was also decided that the following institutions of the respective Member States will be involved in preparation of Agroforestry Diagnosis and Design (D&D) .

- Institute under Ministry of Agriculture Afghanistan
- OFRD, BARI Bangladesh ,
- MoFA Maldives
- RNRC, Yusipang ,Bhutan
- DoF, Sri Lanka
- CAFRI India – Technical support
- Dept of Agriculture- Nepal
- PARC –Pakistan

Considering the capacity of the national program, the involvement of following agencies will be vital to facilitate agroforestry research and development.

- Central Agroforestry Research Institute, Jhansi
- Indian Institute of Forest Management, Bhopal, India
- World Agroforestry Centre (ICRAF)
- KVK based systems with agroforestry expert
- NGOs like Bhartiya Agro-industry Foundation
- Private industries: WIMCO, ITC Paper ltd, BILT Paper board
- International Center for Agricultural Research in the Dry Areas (ICARDA)
- International Water Management Institute (IWMI)
- FAO
- SAARC

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Chapter 1

Technological advancement in agro-forestry systems: Strategy for climate smart agricultural technologies in SAARC Region Synthesis

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Background

The integration of trees into agriculture and social landscape is ingrained into the socio-ecological fabrics of South Asian farming community over centuries. It has not only displayed the inevitable association between men and forest, but also truly helped to sustain farming systems in formidable conditions in the region. The presence of trees in backyard and within the agriculture field is unique in the farms in South Asia. *A dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels* is generally referred as agro-forestry (ICRAF 1996, FAO, 2008). The management of complex agroforestry systems is largely dependent on the optimization of both ecological and social processes (Boni et al., 2004). Among the priority areas to consider in the practice of agroforestry is the harmonious balance between food production and environmental protection.

In this context, soil and water conservation is an important strategy for sustainable crop production and environmental conservation. According to Dennis Garrity (1993), assortment of agroforestry systems has evolved in response to pressure of population on land, technological options and market changes. Traditional knowledge on integration of trees in the farm is so rich in the SAARC Region. All the eight SAARC Member States cover wide range of agro ecological zones, and people have been practicing trees in farm for generations. Agro-forestry is therefore seen as a means of not only improving people's livelihoods through the supply of fruits, timber, fodder and fertilizer and therefore higher incomes, but also in stabilizing erosion, replenishing soils, storing carbon and enhancing on-farm biodiversity. In the present day context, contribution of agroforestry to the mitigation of climate change (through carbon sequestration) is of particular relevance at present as countries attempt to negotiate a mechanism for reducing

emissions from deforestation and forest degradation (REDD+). With the increased engagement of people in forestry management through participatory forestry management strategies, the role of people in developing and applying REDD+ mechanisms has become fundamental. In view of the dynamic socio-ecological interaction and benefits offered by agroforestry, it can be a basis for evolving climate smart agricultural technologies that is able to fulfill the social, economic and environmental benefits for land users at all levels. Agro-forestry is emerging as an enduring technology with ability to help socio-ecological systems develop resilience in the face of changing weather patterns.

Agroforestry is a holistic land use approach in which woody perennials are combined on the same land management unit with herbaceous crops and/or animals, either in the same form of spatial arrangement or temporal sequence. When woody perennials interact positively with food crop farming and/or livestock production and improve the overall performance of the farm enterprise, it may be called an effective agroforestry. A systems approach to any activity starts with the concept that everything is connected and a change introduced in one component will induce a change in other parts of the system. Understanding the linkages between farming systems and agroforestry is extremely important for the success of a farming systems approach involving agroforestry as a component and make climate change resilient. Agroforestry is defined as an efficient, integrated and sustainable landuse system that combines agricultural crops, forest corps and/or livestock together on the same unit of farmland at the same time or in sequential manner. In agroforestry there are both ecological and economical interactions between various components. It is an approach to alternative landuse based on deliberate integration of trees with crops and livestock production systems.

In dry environments, agroforestry systems potentially support livelihood improvement through simultaneous production of food, fodder and firewood without much affecting the climate change. Careful selection of species and good management of trees and crops are needed to optimize the production and positive effects within the system and to minimize negative competitive effects. It is an age old concept where trees, crops and animals have traditionally been raised together on small farms throughout the World. This concept was first practiced in the temperate zone due to the small family farms size. Integration of activities takes place in the land used for agriculture, forestry and livestock in such a way to maximize production of foods and services for diverse requirements of rural communities. Modern agroforestry establishes a symbiotic relationship among agricultural crops, tree species and livestock rearing. In other words, these are complementary and beneficial to each other.

Climate change is one of the greatest social, economic and environmental challenges of our time. Apart from natural causes, anthropogenic factors are the major causes that are affecting the climate to change. This, in turn, is having impacts on rainfall, temperatures, forest fires frequency, health, heritage and biodiversity for current and future generations. Water resources are also seriously impacted around the globe because water is intimately tied to other resources and social issues such as food supply, health, industry, transportation and ecosystem integrity. Human health is affected directly and indirectly by climate change through extreme periods of heat, cold, storms, and climate-sensitive diseases such as malaria, skin related diseases like skin cancer. Mitigation measures can be defined in the context of climate change, as a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Climate change mitigations are actions to decrease the intensity of radioactive force in order to reduce the potential effects of global warming. Climate change adaptation is especially important in developing countries since those countries are predicted to bear the brunt of the effects of climate change. Adaptation alone cannot eliminate climate-related risks completely even with all the possible protective measures put in place. Climate change will impose additional economic, social, and ecological costs.

Over the past centuries, human ingenuity has led to technological advances in agriculture that have allowed substantial increase in crop yields stimulated to meet the requirement of increasing population. Intensive agricultural methods are reported to have detrimental effects on the environment. The agricultural sector has become one of the main driving forces in greenhouse gas emissions and landuse effects

In view of the evolution of agro-forestry systems, a regional consultation meeting was organized in collaboration with SAARC Agriculture Centre, SAARC Forestry Centre and Central Agroforestry Research Institute (CARFI), ICAR, Jhansi, Uttar Pradesh, India, in CARFI campus from 15th – 19th June 2015. The meeting brought together participants from all the eight SAARC member States – Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. The main objectives of meeting are given below.

1. To document the innovative agroforestry practices under the influence of changes (climate, socio-economic, governance) in SAARC Countries
2. To assess the productive and environmental functions of trees in agriculture landscape and its contribution to food security and poverty alleviation
3. To identify emerging issues and propose strategies to develop agroforestry

Agroforestry systems in SAARC Member States

1. Afghanistan

Afghanistan is a landlocked with a population of about 27 million and area of 652,000 km². It is bordered by Pakistan in the south and east, Iran in the west, Turkmenistan, Uzbekistan and Tajikistan in the north, and China in the northeast. Afghanistan has arid continental climate with cold winters and hot summers. The climate varies substantially from one region to another due to dramatic changes in topography. Degradation of environment quality and loss of resources is the big challenge. Between 1990- 2000 Afghanistan lost on an average of 29,400 hectares of forest per year and annual deforestation rate of 2.92 %. Forest now occupies less than 2 % total area of the country.

Afghanistan's agricultural sector is the largest manufacturing sector in the country, which is more than 85 % of Afghans to sustain their livelihoods depend on it, and also has a major contribution to national economic growth. The agricultural sector has almost 7.9 million hectares of arable land, approximately 34 million animals (including poultry) (FAO, 2003), 30 million hectares rangelands and 1.7 million hectares of natural forest and many types of wildlife. In the last 5 decades due to insufficient investments and poor technology transferring, agriculture and natural resources sectors are still operated traditionally which caused unsuitable utilization of markets and production capacities.

Prolonged wars and drought have tremendous affects on natural resources and further forests have been cut for firewood or some timbers are sold illegally. Orchards, vineyards and pistachio forests also suffered from similar adverse affects.

Forest Directorate has started agroforestry in 17 provinces through 360 forests associations since 2013 with an objective to substitute supplying wood and timber need from the agroforestry and should conserve the natural forests. Department distributed 4000 rapid growing seedlings to be planted in about 0.5 hectare by each forest association. People grow seedlings next to their agriculture land. Using this approach, the Forest Directorate was able to afforest above 1 hectare land in 17 provinces of the country. Following this program 800000 pistachio, Pine (Jalghoza), *Amygdalis Communis* (Badam Kohi) seedlings have been distributed in the above mentioned provinces for 200 forest associations to plant them next to their agriculture land. This agroforestry program has progressed well with the local people and forest associations.

Agro forestry is an integrated system of rural land resource management based on combining shrubs and trees with crops and/or livestock .whose interactions generate economic environmental and social benefits. Agroforestry in Afghanistan provide variety of services:

Economic services as follows

- Diversification of economic activities.
- Diversification of agriculture revenues.
- Increase in yield from conventional agricultural systems.
- Reclamation of fragile or marginal lands

Environmental services include:

- Increase in plant and animal biodiversity.
- Decrease in wind and water erosion.
- Improvement in soil fertility.
- Improvement in soil hydrology regimes.
- Mitigation of air sound and outdoor r pollution.
- Water treatment.
- Carbon sequestration and storage.
- Reduction in deforestation.
- Improvement in microclimates.
- Mitigation of climate change impacts on agriculture.

Social services include:

- Job creation.
- Food security.
- Landscape enhancement.
- Improvement in public opinion regarding agricultural and forestry activities.

Land use services include:

- Diversified land use.
- Use of marginal lands (abandoned agricultural land hill slope plots) etc.

Cultural services:

Use of local and indigenous knowledge in agroforestry development offers practical applications supporting the concept of sustainable development. It is also a concrete tool for harnessing the multiple functions of agriculture or so called climate smart agricultural technologies. Government agricultural policies and programs now address economic and environmental functions issues. Crop insurance scheme, soil conservation, biodiversity protection, carbon sequestration etc. have started. Agroforestry on the other hand represents a powerful integration

tool; a variety of objective can be attained simultaneously through the planned implementation of agroforestry systems.

Poplar trees species seedlings were distributed to local people in most of the provinces to encourage planting in the private land. Working tool boxes consist of Pickaxe, shovels, hand carts, mowers, sprinkler, buckets, blades, scissors and thread for farmers were provided to encourage farmer to plant more trees species in their private lands.

Agroforestry development in Afghanistan faces some challenges like

- Poor natural resources management during the civil war.
- Indiscriminate cutting of trees for fuel wood and construction.
- Lack of security in provinces.
- Lack of professional staff, inadequate capacity for data collection and processing
- Lack of harvesting technique to harvest Pistachio nuts.
- Inadequate data or information on percentage or density of forests.
- Converting forestland to rain fed land and settlement.
- Trees or plant disease.
- Forest fire

However, the existing forest policy and strategy support the agroforestry development. Existing forestry rules, rangeland and wildlife conservation laws protects the natural resources for indiscriminate harvesting. Agroforestry system has encouraged forming forestry association and framing its regulation. At present there are about 420 forestry associations countrywide. Distribution of tree seedling to farmers have encouraged local people participation in forest protection and rehabilitation

Few specific recommendations for Afghanistan agroforestry development can be made. It needs a proper plan to generate knowledge through experiences and dissemination, and operational and strategic knowledge acquisition efforts should be developed. A network of demonstration sites should be set up for the various agro-forestry systems applicable to Afghanistan. Interdisciplinary programs and training courses should be developed for professional and technical for employee who works in agroforestry development. Structured funding opportunities for agroforestry development should be explored in the public and private sectors. A comprehensive strategy for agroforestry should be developed under forest directorate of NRM.

2. Bangladesh

The arable land is reducing rapidly in Bangladesh due to high population density and enormous pressure on the natural resources of the country. The arable land is shrinking at the rate of 86,000 hectares every year (BBS, 2008). Bangladesh has only 8.16 million hectares of arable land is one of the most densely populated countries of the world struggling hard to feed her more than 150 million people. A country needs 25% of forestland of its total area for ecological stability and sustainability (Bari and Rahim, 2009). Bangladesh is endowed with only 13.6% of unevenly distributed forests (BBS, 2008). About 7,300 ha of forestland have been lost due to transformation to agricultural land, aquaculture, homesteads and other purposes. Climate change is a very important issue, which needs to undertake appropriate measures to face the escalating issue. Bangladesh is one of the most climate vulnerable countries in the world. Located between the Himalayas and the Bay of Bengal, the country is very prone to natural disasters (World Bank, 2010). Climate change accelerated the intensity and frequency of occurrences of salinity, storms, drought, irregular rainfall, high temperature, flash floods, etc. that resulted from global warming. Global warming is harmful for crops of the tropical countries (UNEP, 2009).

Under these alarming situations, using modern or new techniques must increase agricultural production as well as forest resources. Multistoried agroforestry system is one of them where incorporation of fruits, vegetables, spices and some medicinal plants in these systems can be effective and fruitful. There are about 20 million homesteads in the country, which covers about 0.3 million hectares, Most of the vegetable produced in the country are coming from these homesteads (BBS, 2008). Traditionally farmers grow different types of crops in association with trees in their homesteads. From time immemorial, a large number of diversified tree species are grown in the homesteads and recently many exotic species are included.

A holistic approach to agroforestry systems can be of great significance in this regard by:

- Integrating appropriate species of woody perennials on farmlands along with other components of the farming system not in a competitive but in a complementary way;
- Integrating herbaceous crops and livestock on forest land according to the agroforestry management schemes so as to facilitate simultaneous production of wood and food crops; and
- Employing agroforestry techniques for reclamation of degraded lands and proper utilization of "wastelands".

The Bangladesh Agricultural Research Council (BARC) has identified new potential area of agroforestry research and implemented substantial research and development at cropland, homestead, hill, coastal and wastelands under different ecosystem through its coordinated national research institutes, universities, extension agencies and NGOs. In view of the development of agroforestry systems, it is therefore logical to document the technological advancement in agroforestry practices and assess its relevance as climate smart technologies.

Agriculture is the most vulnerable sector as its productivity totally depends on climatic factors. Rainfall is one of the major climatic factors for crop production. All crops have critical stages when it needs water for their growth and development. Sea level rise affects agriculture in three ways, i.e., by salinity intrusion, by flooding and by increasing cyclone frequency and its depth of damage. Flood has most deleterious effect on crop production of Bangladesh.

Natural calamities intensified by climate change, damage field crops in every year. In 1990's, drought in the north western Bangladesh caused a shortfall of rice production by 3.5 million tones. Unprecedented flash flood in the *haor* areas had accounted for a loss of about 150,000 metric tonnes of rice at the beginning of 2010. It has been reported (Karim and Iqbal, 2001) that salinity affected areas in coastal Bangladesh have increased from 0.83 million hectares in 1990 to 3.05 hectares in 2001. Another study estimated that in eastern Bangladesh alone 14,000 tons of grain production would be lost to sea level rise in 2030 and 252,000 tons would be lost by 2075 (current agricultural production for the country is 30 million tons). OECD referred to a study that estimated a GDP decrease in the range of 28% to 57% from 1m sea level rise (OECD, 2003).

Bangladesh is trying to develop coping mechanism against natural hazards like floods, droughts, tidal-surges etc. through support of the Government. Adaptations to climate change for agricultural sectors includes the resilient crop variety, cropping pattern, irrigation techniques, sustainable land management, early warning, research, subsidies, supply of inputs etc. Researchers of institutions under National Agricultural Research Systems (NARS) are engaged to innovate technologies that will be resilient to climate change and ensure expected crop production. Finance and technology are the means to achieve adaptation and mitigation.

Agroforestry practices are not new in Bangladesh. These were embedded in the traditional forest plantation activities by way of Taungya. In Bangladesh agroforestry has been practiced in various forest plantations. Agricultural crops including paddy, cotton, chilies, sesame, pigeon pea, mustard, maize, and different vegetables have been grown inside the plantations.

Cropland agroforestry combines the production of agricultural crops and trees in the cropland through intercropping like boundary plantation, alley cropping, strip

plantation, homestead garden is most diversified agricultural crops and multipurpose trees fulfills most of the basic needs of the local population and resilient to Climate Change.

In agroforestry practices, trees/plants play vital role in controlling soil erosion mainly through interception, infiltration etc. In Bangladesh, there is evidence that the use of contour hedgerows on steep hill slopes (40- 50%) can reduce erosion by 55-80% and runoff by 30-70% compared to shifting cultivation (Khisa, 2001). Several agro-forestry production techniques, designed with locally adapted trees and crops for different slope conditions, are found to optimize the production of agro-forestry crops and minimize environmental degradation in the hill region of Bangladesh (Paul and Hossain, 2001).

Bangladesh Agricultural University has developed three promising multistoried agroforestry system in three-layered canopy configuration. Three multistoried agroforestry models based on coconut, mango and sissoo has demonstrated beneficial effects in terms of return per unit area and may be adaptive to climate change, and otherwise production may not be high. Coconut based multistoried agroforestry system and this system is economically viable. Nut based multistoried agroforestry system; mango based multistoried agroforestry system, Sissoo based multistoried agroforestry system with integration of vegetables, spices and medicinal plants as ground layer crops in mango based multistoried agroforestry system is clearly preferred agroforestry system. Multi Strata Fruit Orchard (MSFO) an innovative hill friendly agroforestry technology, BARI developed Homestead Agroforestry model for upscaling food security of resource poor rural farming was found promising and viable for raising production, economic return, nutrition supplementation and food security. BFRI developed agroforestry technology for the hill region like differentiated slope agroforestry (DSA) method and natural vegetative buffer strip (NVS) are important. Alternate contour rows of tree plantation along with shade loving crops, bench-terracing method, sloping agricultural land technology (SALT-1 and SALT-2) are useful for climate change scenario.

Bangladesh has great potentials for agroforestry development. Compared to the overall little forest area of Bangladesh, the potential agroforestry land, by any measure, is substantial and amounts to almost 10.4 percent of the country's land surface. If the production potential of this land could be developed, it could dramatically change the production scenarios of both forestry and agricultural products.

The potential arena for the adoption agroforestry technology and subsequent livelihood improvement can be done through adoption of multistoried agroforestry systems in Bangladesh, adoption of planned integrated homestead agroforestry, an appropriate policy intervention for adoption of suitable

agroforestry practices in degraded forestlands, improvement of marketing channel and institutional environment, incorporation of agroforestry in rain fed or dry farming croplands, strengthening social forestry system, capacity buildup of the farmers and strip plantation in new roads and highways

3. Bhutan

Bhutan is a small mountainous landlocked country located in the Eastern Himalayas. It has a geographical area of 38,394 square km and a population of 0.721 million (NSB 2012a). The country is characterized by fragile mountainous ecosystem with elevations ranging from about 100 m in the foothills to over 7,500 m towards the north all within a range 170 km from the northern to the southern border. The most dominant land cover is forest, making up 80.90% of the land area including shrubs which account for 10.43%, cultivated agricultural land and meadows account for 2.93% and 4.10% respectively.

The Renewable Natural Resources (RNR) sector comprises agriculture, livestock and forestry which are closely integrated at the farm level. This sector supports the livelihood of over 69% of the population which are mostly rural based and provides employment to over 56% of the total population. Poverty Analysis Report 2012, (NSB, 2012b) indicates that the poverty of Bhutan has been reduced to 12% in 2012 from 23.2% in 2007. This reduction indicates that Bhutan is well on its way to halving the proportion of the population below the poverty line by 2015. As per 2012 report the national poverty line is Nu. 1704.84 per person per month.

In Bhutan, some of the observed symptoms of climate change impacts on agriculture are loss of crops to unusual outbreaks of pests and diseases, erratic rainfalls, windstorms, droughts, hailstorms and flash floods/landslides that are increasing annually. Most of the farmers are totally dependent on the monsoons for irrigation. The late arrival of the monsoons lead to drought while excessive monsoon rains cause natural disasters such as floods and landslides. Such extreme climatic events also put rural communities at increased risk as many remain disconnected in largely scattered settlements in the most challenging geographic conditions.

Implementation of agroforestry system as a program has not been done in Bhutan at the moment but the systems are being practiced in some form or other since time immemorial. The systems in practice differ based on socio-economic condition of the local people, agro-ecological zones and the land where it is practiced. Agroforestry systems practiced, in Bhutan, can be divided into the following two systems based on landscape niche or the land where the agroforestry is practiced i.e. (i) Farmland based agroforestry systems are Agri-silvicultural systems, Silvi-horticultural systems, Agro-silvopastoral systems like

aquaforestry and (ii) forestland based agroforestry systems like Silvopastoral systems, Trees on rangelands, Non Timber Forest Products collection and Shifting cultivation are quite common. Agroforestry in traditional forest plantations is the system involves raising agricultural crops in forest plantations. Homestead agroforestry or home gardens are usually multi-storeyed mixture of large number of food, fuel, fodder and timber species growing as an intricate crop and producing a wide variety of products. Any types of agroforestry system is beneficial because it reduces pressure on natural forests; more efficient recycling of nutrients by deep rooted trees on the site; better protection of ecological systems; reduction of surface run-off, nutrient leaching and soil erosion through impeding effect of tree roots and stems on these processes; improvement of microclimate, such as lowering of soil surface temperature and reduction of evaporation of soil moisture through a combination of mulching and shading; increment in soil nutrients through addition and decomposition of litter fall; and improvement of soil structure through the constant addition of organic matter from decomposed litter.

The importance of the tree-crop associations has been known through long history of farming systems and the knowledge is handed over to later generations. Therefore the importance of traditional knowledge about tree-crops association cannot be overemphasized. Combination between trees and crops interacts dynamically and provides multi-faceted aspects of improvement such as increased productivity, enrichment of soil with organic matter and nitrogen transport of nutrients from lower layer to upper layer of soil. It will, also help in conservation of environment, improve microclimate of the area.

Bhutan being a mountainous country the importance of controlling soil erosion from the agricultural fields cannot be overstated. Under such scenario if agroforestry is practiced then it has the potential to improve livelihood of farmers, including these young people including school drop outs, by providing multiple products from same piece of land at the same time. Some of the agroforestry options which would be beneficial to farmers are (a) rearing of improved breed of cattle for milk production (b) poultry farming in the backyard for eggs and meat (c) goat rearing for meat (d) vegetable production in the backyard and under shade of trees in home garden.

The different enterprises of farming systems are highly interrelated and linked with each other. Since trees, crops, and livestock are the indispensable components of the farming system, agroforestry has very strong linkage with different components of the farming systems.

Agroforestry technologies suited to different land management systems are available and are in practice. The technologies aim to increase productivity while at the same time conserving the biodiversity, soil erosion control and improving

the fertility and maintaining ecosystem resilience of the area. A standard agroforestry system encompasses synergistic interactions between woody and non-woody components to increase, sustain, and diversify total land output. They involve deliberate retention, introduction or admixture of trees, or other woody perennials, in crop/animal production to benefit from the resultant ecological and economic interactions. Agroforestry research is site specific that is why the technology developed in agroforestry differs in different agro-ecological zones.

Inventory of technologies released for general use are Agri-silvicultural based technology and as a part of the Climate Smart Agriculture Program, Water User Association Guidelines was prepared and based on that manual farmers were trained. Introduction of upland paddy to villages as a solution for production of rice under limited water. The guidelines for vulnerability assessment was prepared with the support of Climate Smart Agriculture support Program for developing adaptation plan. Harvesting guidelines were developed for non-wood forest products for sustainable harvesting.

Silvo-pastoral based technology are developed by research centre in Bhutan and the technologies are well established and used by the farmers. Different agroforestry technologies developed and released by the Research Centers have become boon to the farming communities in Bhutan. The technologies are well accepted by the farmers because they were developed in consultation with them. The impacts has been very promising and good because with the application of different agroforestry technologies the farmers' income level has increased manifold and their living standard also have gone up.

Climate Smart Agriculture (CSA) includes actions at various scales within the full range of the farm plots, farming systems, landscapes, national, and at global level. (FAO, 2014) reiterates that Climate Smart Agriculture approach aims to tackle three main objectives. However the activities undertaken should be within the national food security policy and development goals of the national government. The objectives are:

- sustainably improving food security by increasing agricultural productivity;
- building resilience and adapting to climate change; and
- developing opportunities to reduce greenhouse gas emissions compared to the baseline if possible.

CSA is not a single specific agricultural technology or practice that can be universally applied. It is an approach that requires site-specific assessments to identify suitable agricultural production technologies and practices. The approach:

- a. is a location-specific and knowledge-intensive.
- b. identifies integrated options that create synergies and reduce trade-offs.

- c. identifies barriers to adoption and provides appropriate solutions.
- d. strives to achieve multiple objectives while prioritizing benefits and trade-offs.
- e. strengthens livelihoods by improving access to services, resources and markets.
- f. addresses adaptation and builds resilience.
- g. considers climate change mitigation as a potential co-benefit.
- h. integrates climate financing with traditional sources of agricultural investment.
- i. brings together practices, policies and institutions that are not necessarily new but are used in the context of climate change.

The CSA program implemented by the Royal Government provides services to enhance agriculture productivity and income, through adaptation and building resilience to climate change and reducing greenhouse gas emissions from agriculture. The main objectives of CSA program is to create awareness for farming communities in climate change through capacity building and demonstrations; develop appropriate assessment and planning tools to assess threats of climate change on farming communities; identify and adapt suitable CSA options, mainstream CSA in research and development of the Department of Agriculture.

A better livelihood for the Bhutanese farmers is at the fore-front in planning CSA activities and the same is serviced by working closely with the Ministry of Agriculture and Forests at the national level, and with subsistence farmers, farmers groups, Water Users' Associations and cooperatives through the extension service networks of the Dzongkhags and Gewogs at field level.

The CSA approach in Bhutan is on pilot sites, where farmer groups undertake specific adaptations and mitigation measures aligned to socio-economic and agro-ecological situations. A more productive and resilient agriculture is built on the sound management of water, pests-diseases and soil fertility. Therefore in order to draw comparison on the potentiality of agroforestry as CSA technology, it is important to recognize the emerging concept CSA. Agroforestry has the potential to increase the resilience of crops/trees to climate change impacts.

There are many constraints for up-scaling this program in Bhutan. Some of the important constraints are enumerated below:

- (1) The land holding of the farmers, in Bhutan, is very small and being a mountainous country the fertility of the soil is also very low. Water has become a limiting factor in almost many villages.

- (2) Technical capacity to produce short rotation seedlings of important fodder and fruit trees are lacking. Further it is aggravated by huge cost of seedling production which the farmers are not able to afford.
- (3) Being a very mountainous country, the transportation facility for the farm produce to the market is very limited. Farmers do not feel encouraged to produce more vegetables, fruits and food from the agroforestry system because of the transportation and marketing problem. However, in due course of time, this problem will be sorted out.
- (4) There is large-scale rural-urban migration of the young and able bodied people leaving behind old people in the villages. This situation has resulted in farm labour shortage.
- (5) Credit facility to buy land, improved breed cattle, pigs and pullets, is difficult resulting in reducing the buying power of the people and up-scale the agroforestry practices in the villages.
- (6) Lack of co-ordination amongst the relevant Government Organizations like Department of Forests and Park Services, Department of Agriculture and Department of Livestock.

However, there is a huge potential for improvement. It should be understood that agroforestry, like any other system or strategy, will not have all the solutions to climate change adaptation, mitigation and food security. However, agroforestry practices definitely have substantial potential to help small farmers to improve their food security status, wellbeing and the environmental sustainability of their farms and landscapes.

Agroforestry can be foundation of climate smart agriculture and contribute in helping those who depend on agriculture for their livelihoods to better adapt to future climate change.

Agroforestry is an approach to guide actions to transform and re-orient agricultural systems to effectively and sustainably support food security (FAO, 2014). It is widely accepted that agroforestry systems can play an important role in increasing the resilience to climate change impacts generally for small-scale farmers. The climate change is already negatively affecting forestry and agriculture presenting a triple challenge around food security and nutrition, adaptation to climate change and contribution to climate change mitigation. The climate smart agriculture is an important new approach to address food and nutritional security, adaptation and mitigation interventions.

Rather than approaching the solutions of climate change from a perspective of climate smart agriculture technologies alone it is more advisable to look at climate smart agriculture systems including the resources, practices and policies for sustainable outcome. It is important to accelerate an enabling environment that

will speed up the climate smart agriculture practices not only at the technologies but also on the policies level.

The value of climate smart agriculture should go back to the local circumstances like environmental, resilience and enable them to move toward to prosperity. It is necessary to go beyond food security, adaptation and mitigation to satisfy what the farmers expect from climate smart agriculture practices.

In the coming years/decades, agroforestry can offer solutions to many of the issues and constraints outlined above because it has the ability to reduce greenhouse gas concentration in the atmosphere and sequester carbon in addition to producing food and fodder, crops including meat, milk and other products from livestock and fishery components. The contribution of trees, crops and livestock mitigate environmental risk, creates a permanent soil cover against erosion, minimizes damage from flooding and acts as water storage benefitting both crops and pasture.

Agroforestry systems offer an important opportunity for creating synergies between actions undertaken for mitigation and adaptation on climate change which provides opportunities to increase the resilience of agricultural systems. Agroforestry serves to enrich farmers through the harvesting of diverse products at different time of the year. Therefore agroforestry systems has great potential as a tool for climate smart agriculture in Bhutan where more than 69% of its population lives in rural areas and depend on agriculture, livestock and forestry for their livelihood.

4. India

India had taken a lead in agroforestry research since organized research in agroforestry started world-wide about 25 years ago, through industry participation in plantation of commercial tree species through Indian Council of Agricultural Research (ICAR) institutes. To mainstream agroforestry research, the All India Coordinated Research Project (AICRP) on Agroforestry was established in 1983 by the ICAR. Now, about 25 million ha area in the country (8.2 % of the total reported geographical area), is reported under agroforestry in both irrigated and rainfed agriculture which also includes trees outside forests and scattered trees on and off the agricultural fields. Twenty-five years of investments in research have clearly demonstrated the potential of agroforestry in many parts of the country, and some practices have been widely adopted. But the vast potential remains largely underexploited, and many technologies have not been widely adopted. This situation is a result of the interplay of several complex factors. On the other hand, the success stories of wasteland reclamation, and poplar-based agroforestry show that the technologies are widely adopted when their scientific principles are understood and socioeconomic benefits are convincing. India has announced the

landmark National Agroforestry Policy 2014 that aims to mainstream the growing of trees on farms to meet a wide range of developmental and environmental goals.

Agroforestry is a land-use system that involves socially and ecologically acceptable integration of trees with agricultural crop and/or animals simultaneously or sequentially, so as to get increase total productivity of plant and animal in a sustainable manner from a unit of farmland, especially under conditions of low levels of technological inputs and marginal lands. The most common definition of agroforestry is “Agroforestry is a land use system in which woody perennials (trees, shrubs etc.) are grown in association with herbaceous plants (crops and pasture) or livestock in spatial arrangement, in a rotation or both. There are both ecological and economical interaction between trees and others components of the system (Lundgren 1982). On the basis of nature of components following common Agroforestry systems are prevailing in different agro-ecological regions of India:

1. Agri-silviculture (trees + crops)
2. Boundary plantation (trees on boundary + crops)
3. Block plantation (block of trees + block of crops)
4. Energy plantation (trees + crops during initial years)
5. Alley cropping (hedges + crops)
6. Agri-horticulture (fruit trees + crops)
7. Agri-silvi-horticulture (trees + fruit trees+crops)
8. Agri-silvipasture (trees+crops + pasture or animals)
9. Silvi-olericulture (trees + vegetables)
10. Horti-pasture (fruit trees + pasture or animals)
11. Horti-olericulture (fruit trees + vegetables)
12. Silvi-pasture (trees+pasture/animals)
13. Forage forestry (forage trees + pasture)
14. Shelter-belts (trees + crops)
15. Wind-breaks (trees + crops)
16. Live fence (shrubs and under- trees on boundary)
17. Silvi or Horti-sericulture (trees or fruit trees + sericulture)
18. Horti-apiculture (fruit trees + honeybee)
19. Aqua-forestry (trees + fishes)
20. Homestead (multiple combinations of trees, fruit trees, vegetable etc).

Purpose of growing trees by different categories of farmers

Tree-based farming systems integrating trees into agriculturally productive landscape is an age old practice in India. Trees provide farmers with marketable products such as timber, building poles, firewood, animal fodder, fruits, medicine all of which earn extra income. India is a land of small farmers. Generally, small and medium farmers grow the trees on their field for domestic purposes like fuel wood, fodder, timber etc. Trees have both productive and protective role in agriculture system. In productive role, it enhance the productivity of lands and help to meet the increasing demands of human and livestock. Many agroforestry technologies and systems have been developed for different agro-ecological regions of the country and in addition to providing higher returns these systems also ensured livelihood security and a cover against crop failure due to climatic aberrations particularly under arid and semi-arid regions of the country. Few of the important activities and purpose for integrating trees in the land use systems by the farmers for livelihood security are lac cultivation, sericulture, apiculture and gum and resin.

Agroforestry-Environment linkages

The role of agroforestry in protecting the environment and providing a number of ecosystem services is promoted as a key benefit of integrating trees into farming systems. As traditionally employed in India, these benefits were intuitive to the farmers and landowners that managed agroforestry systems, although the scientific evidence to support such benefits is only now coming to light the impact of agroforestry on the environment occurs at a range of spatial and temporal scales; from fine-scale impacts on soil structure and quality to impacts on the environment and society at regional or global scales.

Agroforestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification and buffering of farming systems. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years. First, their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during droughts. Second, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years. Third, tree-based systems have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems. Finally, tree-based production systems often produce crops of higher value than row crops. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with climatic variability.

In reclamation of salt-affected lands, appropriate tree planting techniques and choices of tree species are very crucial for better initial establishment of saplings. Since alkaline and saline soils differ from each other, methods of working the soils will also be different. For example, in alkali soils a hard kankar layer of calcium carbonate is generally found at a depth of about 1.25 to 1.5m. This layer acts as a barrier for root penetration. The layer, therefore, has to be broken first to allow proper development of roots. However, saline soils do not require such preparation, as they do not have any such barriers. These require special techniques of afforestation so that salt contents in root zone are minimized. Shelter belts and wind breaks are effective in control of wind erosion in arid region. Development of wind breaks across the wind direction has been shown to reduce wind velocity by 20-46% and soil loss by 76%.

Agroforestry technologies

Although Agroforestry research in the ICAR system and other Indian institutes and universities has been in progress since early 1950s. Presently there are 36 Centres (11 ICAR Institutes + 25 SAUs) representing all agro-climates in the country involved in agroforestry research. The Central Agroforestry Research Institute was established at Jhansi in 1988. Some of the agroforestry technology developed in different agro-climatic zones is described below:

- Poplar based Agroforestry system
- Alder - large cardamom based agrisilviculture
- Prosopis cineraria based agroforestry for hot arid region of Gujarat and Rajasthan
- Aonla based agroforestry system for semi-arid region

Adoption of technology

The most widely adopted agroforestry technologies are

- MPT-based black pepper based production system in Kerala
- Teak based agroforestry system across India

Agroforestry potential as Climate Smart Agriculture technology

Agricultural sectors must become climate-smart to successfully tackle current food security and climate change challenges. Agriculture, including forestry and fisheries, is crucial for food security and rural incomes as well as other essential products, such as energy, fiber, feed and a range of ecosystem services. Climate-smart agriculture is a pathway towards development and food security built on three pillars:

- Increasing productivity and incomes, enhancing resilience of livelihoods and ecosystems and reducing and removing greenhouse gas emissions from the atmosphere.
- Climate-smart agriculture contributes to a cross-cutting range of development goals.
- There are many opportunities for capturing synergies between the pillars of climate-smart agriculture, but also many situations where trade-offs are inevitable.

Working at the landscape level with an ecosystems approach, combining forestry, fisheries, crops and livestock systems is crucial for responding to the impacts of climate change and contributing to its mitigation. Inter-sectoral approaches and consistent policies across the agricultural, food security and climate change are necessary at all levels. Institutional and financial support is needed for farmers, fishers and forest dependent peoples to make the transition to climate-smart agriculture. Some effective climate-smart practices already exist and could be scaled-up, but this can only be done with serious investments in building the knowledge base and developing technology. Investments in climate-smart agriculture must link finance opportunities from public and private sectors and also integrate climate finance into sustainable development agendas.

Other potential applications of agroforestry are

- Agroforestry for soil and water conservation
- Agroforestry for wasteland development
- Carbon sequestration potential of agroforestry
- Biofuel and bio-energy from Agroforestry

Constraints to up scaling agroforestry

There are number of technical challenges to the introduction and expansion of agroforestry. Many are associated with misperceptions concerning the interactions between trees and crops, and most can be solved through demonstration and training. Many of the obstacles to wider use of agroforestry are related to policies. Agricultural policies often entirely ignore trees on farms, so agricultural authorities do not develop incentives for tree cultivation or include agroforestry in extension and other guidance.

The availability of quality planting material is a major bottleneck in the development of agroforestry systems in the country. The lack of quality material results in poor productivity and low returns.

The lack of well-developed markets for agroforestry products, combined with the emphasis on immediate returns seen in some agriculture projects and the

difficulty many farmers face in investing in activities that have a delayed financial return, force many farmers to rule out agroforestry as a viable option.

Potential for improvement

Agroforestry, like any single coping strategy, will not prove to be the silver bullet to climate change adaptation, mitigation and food security. However, agroforestry practices do have substantial potential to help smallholder farmers and pastoralists improve their well-being and the environmental sustainability of their farms and landscapes. By adopting the recommendations outlined below, we believe that agroforestry can be a cornerstone of climate-smart agriculture and contribute, as a part of larger development initiatives, to helping those who depend upon on agriculture for their livelihoods to better adapt to future climate change.

- Provide an enabling legal and political environment with an overarching national plan, appropriate institutions and effective and transparent governance structures that coordinate between sectoral responsibilities and across national to local institutions.
- Improve market accessibility and development of markets for ecosystem services to enhance income-generating opportunities provided by agroforestry. This can be done through improving infrastructure or more locally through establishing cooperatives that pool resources to access markets.
- Involve farmers and pastoralists in the project-planning process. Those who depend upon agriculture for their livelihoods should be empowered to ensure that development efforts target what is most relevant to local communities and contexts to accomplish agreed goals in the most effective way.
- Improve access to knowledge and germplasm. This has been shown to significantly improve farmers' willingness to plant or cultivate more trees for multiple purposes. Farmer to farmer dissemination and educational visits provide potential alternative mechanisms and increase adoption rates.
- Improve land and tree tenure. This can have a significant effect on farmers' willingness to invest in their land and improve productivity. Reducing state regulation of farmer management, harvesting and selling of trees on their own farms is an important reform needed in many countries.
- Overcome the barriers of high opportunity costs to land. This is a key requirement for successful implementation of climate-smart agriculture in developing countries and to-date it has been given little attention. Many improved management practices provide benefits to farmers only after considerable periods of time. This can be prohibitive for poor households because investing in new practices requires labour and incurs costs that must be borne before the benefits can be reaped. Payments for carbon sequestration

may be an appropriate way of covering the time lag between investing in climate-smart practices and obtaining the environmental and economic benefits.

- Improve access to farm implements and capital. Credits, loans and other forms of access to capital can significantly reduce farmer vulnerability, particularly in combination with insurance schemes that protect against income losses arising from weather extremes.

5. Maldives

The Republic of Maldives is an archipelago of 1192 small coral islands that stretches over 90,000 Km² in the Indian Ocean making the country one of the world's most dispersed countries. There are 187 inhabited islands with a total population of 341,256 (as of census 2014). Apart from Male', islands can be sorted into the following categories: resort, primarily fishing, mixed fishing and agriculture, and predominantly agriculture practicing islands. Majority of the islands depend on fishing and mixed farming. Very few islands have land area bigger than one square kilometre with an average height of 1.5 meter from sea level.

The trees and shrub species in the Maldives are tolerant to salinity as the islands are small and low lying. Salt intrusion into the islands is common in islands during North East monsoon and poorly adapted species are often suffered badly or die in these incidents. Many poorly adapted species are endangered due to the salt intrusion caused by Tsunami 2004. Forests are among the few resources that the people of Maldives have a great dependence on to accomplish basic needs. Coconut is a highest percentage of forest cover in the country and is widely used for coconut palms; coconut and oil as a major food source, palm trunks as timber to build transportation vessels, build up shelter, household utensils, furniture, thatch from palm leaves as roofing material.

Changes in economic, social and demographic settings generate demand for land. Forest lands are mostly cleared for the expansion of agriculture, industrial growth, and development of tourist resorts and to provide housing to cater to the demands of the growing population.

As the dominant tree species in Maldives forestry is *Cocos nucifera*, locally known as “*Dhivehi ruh*”. Although coconut palm is a horticultural species and can't be considered as a forest species, substantive part of the tree vegetation in the islands is pure natural stands of coconut palms. Therefore, the coconut thickets play a very important role in the economy of the island. Most of these stands are immediately behind the littoral forests, on the landward side of the island and acts as an effective coastal shelterbelt.

Some of the major systems of Coconut based Agroforestry currently practiced in the Maldives are as detailed below:

- Coconut based annual crop Agroforestry systems – where intercropping with annuals such as cassava and vegetables, Compared to coconut monoculture, which is rarely practiced in Maldives, and the land under Agroforestry are more favorable and stable for sustainable agricultural production. The system helps to diversify and integrate the components within the system, and support sustainability.
- Coconut based perennial crop Agroforestry systems – farming system in which perennial or semi-perennial trees are grown together in mature coconut stand of 20-25 years and above.
- Coconut based coastal Agroforestry system –coconut based coastal Agroforestry systems will supplement ecosystem services provided by mangrove and coastal vegetation systems and make an important interplay with highly urbanized systems.
- Coconut home garden Agroforestry – This system compromise of a variety of tree crops with multiple uses (perennial food crops, fruits, vegetables, roots, tubers, medicinal plants).

All those agroforestry systems make the nutrient cycle becomes more effective as tree components deep root systems absorb and recycle nutrients from subsoil that would have been otherwise loss by leaching. Net income from a unit holding under Agroforestry system provides high consistent income than mono-cropping. It ensures reasonable cash flow during the pre-bearing period. It creates favorable microclimate for the coconut and various level of shade loving understory crops by increased utilization of sunlight, reduced so temperature, and also increased soil moisture over coconut monoculture system.

Agroforestry systems can play an important role in the adaptation to climate change by changing the micro-climate, protecting the environment by provision of permanent cover, improving efficiency of the use of soil, water and climatic resources, reducing carbon emission.

The technologies in the agroforestry systems in Maldives are basically two ways of managing trees for forage. The first way is the animals graze the trees in the paddock or forage is cut and carried to the goats. The main forage legumes used are *Leucaena leucocephala* (locally known as *ipil ipil*) and *Gliricidia*. Other potential tree legume species include *Sesbania grandiflora* (locally known as *feerumura'ga*) *Albizia saman* (locally known as *bodu gas*), *Pterocarpus indicus* (locally known as *Ofi eley gas*), and *Moringa oleifera* (locally known as *muran'ga gas*). *Hibiscus tileaceus* (locally known as *dhiggaa*) is also a suitable

dry season fodder. These trees has a deep rooting nature therefore it is beneficial in the dry season for maintaining protein, energy and mineral supplies in grazing goats. Crops form the lower level of the canopy while trees form upper level of the canopy is good combinations; trees provide shelter for the crop and reduce potential damages caused due to high wind.

Potential food crops that can be integrated into Agroforestry systems in the Maldives are Taro (locally known as *ala*), Yam (locally known as *ka'tala*) and Cassava (locally known as *dhandi aluvi*)

For the last couple of years, extensive damages have been caused to crops at different parts of the country due to strong winds. Salt spray from the ocean breeze had caused burning of the crops. When land is cleared for any agriculture purpose it is important to keep in mind to protect the farmland from natural windbreaks.

Agroforestry potential to be a Climate Smart Agricultural Technologies is to deal with agriculture, weather smart, water smart, carbon smart, energy smart, and knowledge smart. This should benefit both farmers and society. It is an everyday challenge for us to meet the climate risk in a ways in which it is environmentally safe and environmentally sustainable. Better Research programs should be conducted at Agriculture research center located at Hdh. Hanimaadhoo in order to address climate change, agriculture and food security issue. Work needs to be undertaken to develop “climate Smart Islands”. These will be sites with diverse rate of stakeholders converged to strategies about the best interventions that will fit to the local context. The idea is that climate smart technologies and climate information services to be integrated into island development plans. Using local knowledge supported by local institutions.

Climate smart Islands models can be started by creating corporative societies that consists of farmers, researcher and island council officials. Begin prioritizing climate smart technologies that can be adopted by the farmers; feasibility studies needs to be undertaken, such studies should be participatory and inclusive. Capacity building programs on gender and climate change for farmers and climate smart islands. Farmers in climate smart islands implements a range of technological and institutional interventions such as value added service (weather forecast), floods insurance scheme (allied insurance scheme), efficient irrigation management systems , adaptive cultivars , conservation management based agriculture practices, and range of other low greenhouse gas emitting options. Adopting strategies that maximize synergies between adaptation, mitigation, food production and sustainable development are very important. Climate smart islands will be an example by increasing food production while remaining environmentally sustainable. Such models will be demonstrated in north, central and south around 60 farmers of Maldives.

Several challenges can be identified in up scaling Agroforestry system in the Maldives. Coconut is a rain fed crop, longer dry periods due to adverse weather will impact heavily on coconut production when intercropped, and due to poor soil conditions and limited ground water availability it will be hard to adopt such kind of system. Lack of department involved in Agroforestry research in coconut lands and poor research and extension linkages, and lack of knowledge and capacity of the people working in the field. Most of these systems require management of crops, trees and its inputs and skilled knowledge compared to monoculture. Land tenure is another pertinent issue for the development of agroforestry that is resilient to climate change. Pest resistance varieties may be carefully introduced and encouraged.

However, there is a huge opportunity for improvement. As coconut is the dominant forest tree in Maldives, ways in better utilizing the existing natural stands is vital. It is important to improve the coconut industry in the country.

It is important to create awareness amongst farmers to increase productivity of the coconut stands. Such initiatives have already been taken by the government by the commitment made to celebrate this year's agriculture day targeting coconut palm. In this paper we will be highlighting ways in which the coconut harvested by an Agroforestry can be used as a sustainable climate smart agriculture technology.

There is large potential for developing poultry farming in Maldives. "Free range poultry farming in coconut lands". This system can be considered as an environmentally friendly organic farming, this system would reduce poverty among rural community. In such a system *Gliricidia* serve as a multi-purpose and fertilizer tree component in coconut stand. *Gliricidia* is known as green manure tree and is a cost-effective method of fertilizing in coconut plantation.

Tethering system can be applied in Maldives, especially under coconut plantation with jungles. Goats are generally kept in small or medium size (up to 10 animals). 40-50% of daily fodder requirement of goat can be met through tethering and the rest of the feed can be supplied under stall-feeding. It is important to keep the goats in the shed during the night time, and supplementary feeding is required, during the rainy season the goats need to be stall fed, fresh water and mineral lick shall be available at all times.

Leucaena leucocephala is well adapted to soil in pH range 6-8, therefore is best suitable for coralline derived soils of pH 7.5 and greater like in the case of Maldives. The Optimum rainfall range is between 1500-2000mm per year for growth of the tree. In 2014, on an average Maldives experience 2133mm of rainfall. For maximum growth *Leucaena leucocephala* requires high level of calcium and phosphorus.

In conclusion, it has been identified that shift from coconut monoculture to coconut based Agroforestry as a national priority for the future development

strategy for coconut sector due to higher population, land degradation, low productive coconut stands. New land for agriculture is not an option now, yet the demand for coconut is increasing.

Mapping of coconut based Agroforestry and identify sustainability of Agroforestry products is important. This demand for greater interdepartmental collaboration, creating a need for a new collaborative approach rather than distribution of fruit trees/ plant seedlings.

Coconut growers who store carbon in trees, crops and soils should be rewarded with awards “fehi Fai” on world food day (16th October) / Agriculture day (10th August). Right policy support will be critical in meeting potential of coconut Agroforestry to fully develop in Maldives. Furthermore, Regional collaboration with countries that already have well-established agroforestry systems can help capacity building of extension staffs and farmers. Therefore, linking and networking is critical to share information and exchange technological skills.

6. Nepal

Nepal is a land-locked country occupying the central part of the southern slopes of the Hindu-Kush Himalayan arc occupying an area of 147,181 square kilometers between India and the Tibetan Autonomous Region of China. The altitude ranges from around 60 m in the Terai to more than 8000 m in the High Himalayas. Most areas fall within the sub-tropical monsoon climatic region, but because of its wide range of topography, precipitation varies greatly from one place to another. The average rainfall ranges from 250 mm to 4500 mm. The economy of Nepal is primarily based on agriculture; about 80% of the population derives its main livelihood from farming. The 39.6 % land is under forest and 21% under cultivation.

Tree on farmland is an age-old practice but now is gaining momentum because it has a number of social, economic and ecological advantages from both the farmers and the nation's point of view. Crop production, livestock and forestry have been closely integrated and interlinked in the farming system, each supporting the other. The aim of developing Agroforestry technology in Nepal is to meet the present and future requirement of fuel wood, fodder, small timber, food and environmental protection in rural areas (Amatya 1999). Finding alternative options to increase the supply of forest products to support rural livelihoods have become a fundamental concern for policy makers and planners. Nepal's government policy emphasizes the need to initiate community and Agroforestry programs (MPFS, 1991; Shakyaa and Baral 2006). Furthermore, Agroforestry are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration, and that can also strengthen the system's ability to cope with adverse impacts of changing

climate conditions (Verchot et al.2007). Research on Agroforestry research and development; however, there is no clear-cut policy and program for research and development of Agroforestry system in farm land. Paudel (1997) reported that government based institutions such as Department of Forest Research and Survey (DFRS) and National Agriculture Research Council (NARC) has mandate for Agroforestry research but which institutions is responsible for what is often confusing. Furthermore, Agroforestry research is relatively new approach and location specific, the research aspect has not received much attention at policy and planning level (Baral and Shakya, 2006).

Nepal has various types of agricultural zones like plains, hills, mid hills, high hills and mountains. Changes in agro-zones lead to the change in cropping pattern of the zone.

B.R. Regmi and A. Adhikary in 2007 reported that climate change is posing threat to food security due to loss of some local land races and crops in Nepal. NINC (2004) states that with the increase of temperature beyond 4 degree Celsius, the yield of Terai rice is projected to decrease.

Agroforestry systems in Nepal in the broadest sense encompass a wide range of production systems, from forest to crop monoculture. The most common criteria for the classification of Agroforestry systems are the structural basis, in which components of Agroforestry (forestry, agriculture and livestock) are combined. Other criteria include its function, socio-economic scale and management level and ecological basis. The major agroforestry systems of the High Mountain and mid-hills of Nepal are home gardens, agri-silviculture system (planting trees along terrace bunds, borders and slopes), silvi-pastoral system (kharbari), agri-silvi-pastoral system (typical hill farming, in which agriculture crops are grown on terrace flat, trees on terrace bunds and borders, and grasses on terrace slopes-kanla), and alley cropping (promoted by the Leasehold Forestry and Livestock Program/FAO), where as this in Terai and inner Terai are home gardens, agri-silviculture system, silvi-pastoral system, horti-silviculture system and silvi-fishery or aqua-silviculture. Taungya system was also practiced in Terai and inner Terai of Nepal for plantation establishment. Shelter belt establishment and management practice is common in fruit orchard of Terai and inner Terai of Nepal. Apiculture, sericulture, and shifting cultivation can also be considered as minor agroforestry systems.

Agroforestry systems of Nepal differ in socio-economic condition of the farmers and ecological zone. Agroforestry practices in Nepal can be described in two broad categories: farm –based and forest-based. **The farm-based practices** are home gardens, planting trees on and around agriculture fields, tree wood lots and commercial crop under shade trees or agriculture crops inter-cropped with commercial trees. **The forest-based practices** involve specific agricultural

practices, medicinal plants associated with forests where farmers collect food, fruits and gums (Tejwani and Lai, 1992). These practices involve specific agricultural practices associated with forests where farmers collect food, fruits and NTFPs.

Framing system is very complex and of subsistence type with a mutual-interdependency of crops, livestock and forest resources being integral part of farming system, just as much as arable land and livestock. Agroforestry optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops. The benefits created by Agroforestry practices are both economic and environmental. Interactions between the tree and crop components can be positive, negative or neutral. Kaushal and Verma (2003) reported that Hill farmers, irrespective of size of landholdings retain few trees on farmlands. These trees not only provide fuel wood, fruits, fodder and timber but are also helpful in bringing microclimatic changes by reducing soil and air temperature, irradiance and wind speed. However, retaining these trees normally requires a price in terms of competition for moisture, light and nutrients for the field crops. Understanding the degree of competition in these systems can provide the base line data for determining the optimum tree density, devising suitable management options and to maximize the resource use and productivity of the systems.

The perception of people on planting trees on their farm land was assessed by classifying the farm land as bari, khet and home garden. It is reported that trees cast their shades and increase light, root and moisture completion with the main crops decreasing the productivity of the land. However, people were aware of the economic and environmental benefits of Agroforestry practices and had favorable attitude towards those practices. Most people agree that Agroforestry practices increased soil fertility, increased farm income and reduced the chances of complete crop failure. The respondents realized that plantation of trees on the underutilized portion of the farmland has not decreased in the overall output of the farmland. This practice has reduced the chances of complete crop failure.

The vegetation covers and protects the soil from extreme heat and cold. Agroforestry systems play an important role in arresting and reversing land degradation via their ability to provide permanent cover, improve organic carbon content, improve soil structure, increase infiltration, and enhance fertility and biological activity. Agroforestry systems with the combination of legume and non-legume tree and crop species not only improves and sustains soil fertility, but also reduces soil erosion and land degradation. In Nepal, shelter belts and or wind breaks are maintained in Terai and inner- Terai regions where strong hot and dry wind damage agriculture crops and fruits. *Eucalyptus camaldulensis*, *Casuarina equisetifolia*, *Dalbergia sissoo*, *Acacia auriculiformis*, *Melia azaderach*,

Leucaena leucocephala and *Bambusa* species are mostly planted as wind break and or shelter belt. Trees, crops, and livestock are the integral components of the complex Nepalese Hill Farming System. Agroforestry practice in Nepal has helped millions of farmers to generate the cash income through forest products such as firewood, fodder, Non-Timber Forest Products (NTFPs), etc. and enhance wild biodiversity by conserving the habitat of wild birds and animals. Some practices of agroforestry systems in Nepal is mostly alley cropping and homestead production system. Horticultural and pasture species have been planted to fill the big gaps. Type and density of species combination depends on leasehold families' preference on species and nature of ecological need of the species to suit in the existing gaps between trees. For example, in many leasehold forests, strong light demanding lemon grass was introduced in open gaps, whereas forage species, such as stylo (*Stylosanthes guinensis*) was planted in smaller gaps in between trees as these forage need less light compared to lemon grass. Multipurpose tree species, *Artocarpus lokoocha* was introduced as an enrichment plantation; nitrogen fixing *Leucaena sp.* and molasses (*Melinis minutiflora*) were planted in open deteriorated micro-sites to enrich soil. For the first two years, tree seedlings were smaller and were surrounded by pasture species. As seedlings attained height, pasture species did not spread close to tree seedlings growing instead only in-between the tree rows. There is no fixed geometrical configuration for plantation, and hence species have been introduced following the presence of existing natural tree patterns. Trees have been planted in rows, and perennial pasture species have been introduced as understory ground cover between tree rows in completely bare forest lands. In Nepal, the International Centre for Integrated Mountain Development (ICIMOD) and the National Agriculture Research Council (NARC) have been instrumental and active in testing various SALT options over the last few years and have found that these technologies are effective in conserving soil and water, enhancing soil fertility and increasing crop production.

SALT 1, SALT 2, SALT 3 and SALT 4

The practices such as organic and integrated farming system, farmers' managed irrigation system, crop residue mulching and indigenous knowledge should be promoted as a part of CSA.

Some Agroforestry potentials which are being adopted as CSA technologies in the country are trees grown in different regions are Terai (*D. sissoo*, *Eucalyptus*, *Melia azaderech*, *Leucaena* etc) hill (Mainly fodder trees such as *Artocarpus lakoocha*, *B. purpuria*, *B. variegeta*, *Leucaena*, *Morus alba* etc) and mountain fodder trees such as *Saurauia nepaulensis*, *Ficus* etc. Silvi-pasture potentials is common in all agro-ecological zones of Nepal, where land is marginal for crop production. In mid-hilly region, land having grasses is known as kharbari. Trees

grown in kharbari in different regions are Terai (*D. sissoo*, *Eucalyptus*, *Leucaena* etc), hill (mainly fodder trees such as *A. lakoocha*, *B. purpuria*, *B. variegeta*, *Leucaena* etc and timber species like *Schima walichii*) and mountain (fodder trees such as *S. nepalensis*, *Ficus* sps., *Quercus* sps.etc. The main advantages of this system are as follows:

- Produce multiple products such as fodder and forage needed for livestock, fuel wood, timber, and leaf litter needed for organic manure production.
- Improve and sustain the livestock productivity which increases the level of income of the farmers.
- Improve the nutritive value of animal feed due to the regular supply of green fodder.
- This is also the best practice for soil nutrient recycling, which also helps to reduce chemical fertilizer purchase.
- Improve the farm site ecology by reducing surface run off, soil erosion and nutrient loss, gully formation and landslides.
- Improve the local micro-climate and enhance the productive capacity of the farm.
- Reduce pressure of community forests and other natural forests for fodder, fuel wood and timber.
- This practice helps for the beautification of the surrounding areas.

Agro-silvi-pastoral and horti-silviculture system are good practices in the climate change scenario. This system is defined as growing of trees and fruit trees or ornamental trees or vegetables/flower together in same lands at the same time. This system is common in Terai and Inner Terai of Nepal, where trees such as *Sissoo*, *Eucalyptus*, *Melia azaderech*, *Leucaena* species etc are grown around fruit orchard that act as shelter belt. In eastern Nepal, cardamom is planted as an under storey with *Alnus nepalensis* trees. Similarly, *Albizia* and *Sissoo* trees are planted for providing shade to tea, and *Leucaena* is the best trees for providing shade to coffee plants. The main advantages of this system are as follows:

- Produce multiple products such as fruits, fodder and forage needed for livestock, fuel wood, timber, and leaf litter needed for organic manure production.
- Improve and sustain the fruit/vegetable productivity which increases the level of income of the farmers.
- This is also the best practice for soil nutrient recycling, which also helps to reduce chemical fertilizer purchase.
- Improve the farm site ecology by reducing soil erosion and nutrient loss.

- Improve the local micro-climate and enhance the productive capacity of the farm.
- This practice helps for the beautification of the surrounding areas.

Silvo-fishery or aqua-silviculture is known as silvo-fishery or aqua-silviculture. In this system, trees and fruit trees are being planted along the embankment of the fish pond. This system is popular in Terai and inner-Terai of Nepal, where trees and fish included in the same system. Tree species grown along the embankment of fish pond are *D. sissoo*, *Eucalyptus*, *Melia azaderach*, *Leucaena species* etc and fruit species are Banana, Papaya and Pine apples. Extra income can be generated from trees, fruits, ducks and pigs.

Multistorey Agroforestry controls soil erosion, moderates surface soil temperature, suppresses weeds, recycles nutrients and preserves moisture. Major constraints to up scaling Agroforestry systems in Nepal generally fall into the following categories: biophysical, technical, economic, social and cultural, institutional and infrastructural, which are briefly discussed in following section:

Since Agroforestry promotion program has been given less attention and research findings also do not meet so far farmers' requirements, so there is a need to enhance Agroforestry technologies among the farmers by developing mechanisms to link farmers' interest and scientist's knowledge; proven to yield significantly and immediate economic benefit to farmers. There is a need to link Agroforestry system to improve livestock based production system (there is huge contribution of Community F and LF in reducing poverty in Nepal by promoting livestock) by supplying green fodder and forage during feed shortage periods.

Farmers of Nepal have been practicing different Agroforestry models in different geographical location. Agro-forest supplies fodder, fuel wood, timber and fruit for rural household consumption. Home garden, hedgerow intercropping, trees in and around the agricultural fields, grasses with trees in *kharbari* land are the common Agroforestry practices in Nepal. The integrity of crop, livestock and forestry components to fulfill the livelihood needs of resource poor farmers and maintain the ecological stability is obvious in farming system. The linkage of these three components has enabled the Nepalese farmers to survive throughout the history. It reveals that Agroforestry innovations provide options for reducing poverty, improving food and income security and sustaining environmental quality. Degradation of the forest resources and increasing demand of the forest product posed the great challenges to sustain the rural livelihoods. Moreover, Agroforestry management systems offer an important opportunity for creating synergies between actions undertaken for mitigation and activities undertaken for adaptation on climate change that also provide opportunities to increase the resilience of agricultural systems. In this context, promotion of the Agroforestry technologies in rural farming is an important component to improve rural livelihoods and for

environment conservation. Similarly, appropriate policies are still needed to enhance Agroforestry practices.

7. Pakistan

Pakistan is an agricultural country, with over 47% of its population earning their livelihood from agriculture. This sector contributes 24% to GDP (Economic Survey of Pakistan, 2013). It is the largest source of foreign exchange earnings and meets raw material needs of country's major industries. The growth in the agriculture sector increased from 0.6% to 1.2% during the recent past. The Indus Valley, which is the cradle of Pakistan's agriculture, is currently under threat by climate change which is largely induced through anthropogenic interventions resulting in global warming. While higher concentrations of carbon dioxide can have some positive effect on crops, rising temperatures and reduced precipitation can play havoc with the biological complex (IUCN, 2009).

Improved growth in agriculture sector is attributed to the government's agricultural policy reforms such as waiving of interest on loans, support price policy of wheat and introduction of micro credit facility. The growth is also attributed to timely measures to get cotton out of deep-seated crisis. Wheat is the principal food and commercial crop and occupies about 37% of the total cropped area.

Pakistan is regarded as a country with very low forest cover with only 0.03 ha of forest per capita as compared to the world average of circa one ha. The contribution of forestry sector in the Gross National Product of the country is only 0.3%. Population of Pakistan is growing at a rate of 2.6% per annum resulting in declining in the per capita forest area. Expansion in the area of public forests is not possible; however there is a vast scope of growing trees on agricultural land which can contribute substantially to the ever increasing demand of wood production (Pakistan National Forest Policy, 2010).

More than 90% of the fuel wood requirements of the country are met by trees outside forests. The need of promoting tree plantations on agricultural land been recognized for a long time to fulfill the ever increasing demand of fuel and fodder. Since the very beginning of the creation of the country, tree planting has been encouraged by providing the saplings of multipurpose tree species free of charge to the general public. The 1955 forest policy recommended block plantations by farmers' cooperatives through their education and extension.

Agroforestry can be defined as a deliberate integration of woody components with agricultural and pastoral systems on the same piece of land either in a spatial or temporal sequence in such a way that both ecological and economical interaction occurs between them (Kalinganire et al., 2008). Agroforestry has been practiced traditionally in Pakistan since times immemorial to harvest multiple benefits from

the same piece of land. Trees on agricultural land are very important asset which supply economic returns to the farmer in case of crop failure or supplement their income.

Agriculture is both directly and indirectly affected by the climate change, by change in soil water relations, shift in carbon and nitrogen cycles, directly influencing crop growth and development and increased incidence of weeds, pests and diseases. These effects are further exacerbated by means of increased heat stress, increased evapotranspiration, shortened growing seasons, increased photosynthetic activity and reduced water use due efficiency due to increased carbon dioxide in the atmosphere. Impacts of climate change on agriculture has been assessed and is generally agreed that the following major challenges will be faced by the agricultural systems as a result of climate change (Reilly et al., 2001; Das, 2003).

1. Due to an increase in average annual temperature in the northern parts of the country, cropping area may extend/shift towards north
2. Water requirement of crops will likely to increase as a result of higher evapotranspiration demands
3. Reduction in the amount of plant available water in most places.
4. Extreme events of floods and cyclones may result in increased degradation of land resources due to accelerated soil erosion
5. Incidence of weeds, new pests and diseases will likely to increase
6. Cost of input may rise due to increase in energy and other input costs
7. More land will be required for future needs of biofuel production resulting in increased food prices which may have adverse impact on accessibility of food to the poor
8. Genetic erosion may lead to decrease in biodiversity resulting in extinction of some vulnerable species

Pakistan is rated among the top 10 most vulnerable countries to climate change as per independent international assessments such as that by German Watch, an NGO based in Germany.

Major concerns are Increased variability of monsoon pattern which may be delayed, retreat of Hindu Kush Himalayan glaciers affecting Indus River System Flows, increased occurrence of extreme events of floods, droughts, cyclones, extreme high / low temperatures cloud burst etc., arid and semi-arid regions of the country will undergo severe water and heat stress which may lead to reduced agricultural productivity, increase in deforestation/ degradation of forests and threat to biodiversity, penetration of brackish water into the Indus delta as a result of rise in sea level rise resulting in great risk to mangrove forests and breeding grounds some species of fish, and health hazard to human beings and livestock

Climate change is posing serious threats to farmers of Asia especially those living in the marginal areas such as mountains, dry lands and deserts areas that are deficient in natural resources. The agriculture sector is economically more vulnerable as a result of climate change. Pakistan is at 28th place among the countries which are most vulnerable by climate change.

Agroforestry has the potential to adapt to the challenges of climate change. One of the important practices can be the growing of fast-growing, nitrogen fixing trees and shrubs in agricultural fields to improve the soil fertility but will also arrest the soil erosion. In this way, agroforestry systems the most valuable adaptation measures in making communities resilient to the impacts of climate change and do discuss the same in relation to the challenges posed by the changing and variable climate (Rao et al., 2007).

Apart from meeting the vital requirements of food and income, Agroforestry systems have profound environmental benefits. If practiced with care, tree and crop species selected can meet farmer's needs for food and cash. However, the environmental benefits from agroforestry systems far exceed the economic returns. During the recent past, environmental services such as carbon sequestration, watershed protection and biodiversity conservation have become a top priority and these are being financed by the international agencies. It has been estimated that the carbon payments are sufficient to help to smallholder agroforestry farmers increase production. Agroforestry system is in the most efficient in bringing positive changes in all these conditions. Agroforestry systems involving contour hedgerows and presence of trees and shrubs can play a very important role in halting and even reversing land degradation because they provide permanent soil cover, increase organic carbon, improve soil structure by increasing organic matter, increase infiltration of water and also increase soil fertility (Rao et al., 2007).

Agroforestry has been included in the traditional landuse by the subsistence farming community all over the world. In Pakistan, farmers have been growing trees in association with the field crops, vegetables and other horticultural crops to meet their domestic needs (Amin, 1981). The objectives of the agroforestry systems are to maximize the positive interaction of the resources to harvest a higher and sustained productivity, thus improving the livelihood. Agroforestry systems include but are not limited to subsistence livestock silvo-pastoral systems, home gardens, timber production at farm level, trees integrated with crops and biomass plantations. Agroforestry systems are found in a wide diversity of biophysical conditions and socio-ecological characteristics. Some the agroforestry practices in Pakistan are tree planting campaign in the thal desert, poplar on farmlands in peshawar, fruit and forest trees in swat valley, *eucalyptus camaldulensis* shelterbelts and agricultural crops in sindh, *acacia nilotica* block

plantation (hurries) in sindhsimal (*bombax ceiba*) and cotton, shisham (*dalbergia sissoo*) on farmland turmeric and poplars, mulberry for silk production and basket making, *tamarix aphylla* shelterbelts in thal, block plantations of ipil ipil on private lands

There are a number of ways and means through which soil fertility can be maintained and/or improved under agroforestry systems. Atmospheric nitrogen fixing legumes improve the N status of the soil, and also improve nitrogen nutrition and yields of associated crops on under nitrogen deficit conditions of low application of nitrogenous fertilizer. The reduction of nutrient leaching and recycling of subsoil nutrients by deep-rooting trees can improve the availability of nutrients in the system and reduce negative environmental impacts (Vohland and Schroth, 1999).

At present, there is no system of release of agroforestry technologies, however, many systems including hedgerow intercropping, shelterbelts/windbreaks, home garden, Taungya, growing fruit trees, Fodder banks/protein banks, boundary planting on croplands, establishment of living fences, etc. have proved to be economically viable and are being practiced in various parts of the country.

Potential of agroforestry potential as Climate Smart Agricultural Technology is huge. The FAO defines 'climate-smart agriculture' as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goals." (Lipper, 2010). This means that environmental and sustainable methods of farming must be adopted to meet the future needs of agricultural products food, feed, fiber and timber. Climate-smart agricultural practices not only focus on mitigation and adaptation strategies but also provide other benefits. These include: Increased resilience as a result of climate change, reduction in greenhouse gas emissions and improvement in food security.

Although, the natural forest ecosystems are the largest vegetation on earth which provides carbon sink, however, this vast natural resource is under threat due to deforestation and degradation of forests especially in developing countries of the world like Pakistan. It is very difficult to restore these deforested and degraded sites to their original condition. Hence, there is a need to transform tree based carbon rich ecosystems like plantation forests and agroforestry as carbon sink. Agroforestry systems are spread over one billion ha in different ecosystems all over the world have attained a special significance in this regard.

The trees and shrubs in agroforestry systems have the capacity to store the atmospheric carbon dioxide in plant biomass and soils. Agroforestry systems offer important opportunities of can create synergy between mitigation and adaptation actions with a huge potential in the terrestrial ecosystems in the future. If an additional 630 million ha of unproductive croplands and grasslands is converted

into agroforestry system, magnitude carbon sequestration can be enhanced to a great extent. The total above and belowground carbon storage in biomass in agroforestry systems is always higher than croplands. Under various agroforestry systems have increased expectations of carbon sequestration especially in developing countries like Pakistan.

Climate smart agroforestry system of the future will include boundary trees and hedgerows for nutrient recycling, growing nitrogen-fixing trees on farms for enhanced soil nutrient, introducing multipurpose and fruit trees for livelihood improvement, improved fallow with fertilizer shrubs and woodlots for carbon sequestration.

However, there are challenges to advance CSA agroforestry development. The main reason for non-adoption of agroforestry by farmers is lack of awareness. Many farmers are of the view that growing trees on farmland is detrimental to the crops (Nauman et al., 2008). Amir (2003) has also reported that lack of education was the main reason of not adapting the agroforestry and that educating farmers was the only tool to persuade farmers to grow trees in association with crop for better income generation

Farmers are of the view that trees compete with crops for water and nutrients. Many farmers in the Punjab province of Pakistan do not grow trees because of having small land holding and they want to practice intensive for their livelihood. However research has revealed that growing crops under monocultural system, the natural resources are not utilized fully. On the other hand, through agroforestry systems the farmers can utilize soil resources in a better way and get maximum economic returns (Nair, 1996). Some farmers are of the view that marketing of timber and other tree products is difficult as compared to crops (Nauman et al., 2008) and farmers will show more interest to grow trees with their crops if better marketing and economic benefits are ensured. Jamil (2003) also concluded in his study that a majority of the respondents were hesitating to grow trees on their farmlands because they hindered the agricultural crops.

The farmers generally believe that the trees planted along with agricultural crops damage the crop production and affect the economic returns. Many agronomists are also against including trees in crops because they think that trees retard crop growth through competition and they provide shelter for birds.

Agroforestry in particular has a great role to play in the accumulation and mitigation of atmospheric greenhouse gases (IPCC, 2000). Compared to all other types, agroforestry has been considered to have the highest potential for carbon sequestration because the system offers the opportunities of synergies between both mitigation and adaptation. Potential for further improvement lies in the fact that agroforestry can provide food security in terms of enhanced food availability, security of land tenure, increased farm income as a result of balanced resource

utilization, restoration and maintenance of biodiversity and maintenance of watershed hydrology and soil conservation.

In conclusion, during the past three decades, it has been proved beyond a shadow of doubt that global warming and its impact on the agro-ecosystems is real. Pakistan is included among the top 10 countries which are most vulnerable to climate change. The impact of climate change on the agricultural systems are of the great concern to the developing countries like Pakistan as economy of Pakistan is dependent of agriculture, very low capacity to adapt and little support from the government. Agroforestry systems offer a win-win scenario as they act sinks for atmospheric carbon at the same time help attaining food security especially to small farmers, enhance farm income, improve soil fertility and offer better environmental conditions.

An assessment based on in-depth knowledge and scientific data is necessary for a realistic assessment of the complex associations and interactions of this vast natural resource base and allied socioeconomic and environmental benefits. To study these very complex agroforestry systems thorough collecting data of complete rotations involving all components of the system is needed. Member states must support long-term research because much of the current knowledge is based upon incomplete data. In addition to an in depth understanding of the benefits from the systems and farmer requirements, mainstreaming of agroforestry requires better market linkages must be provided for the goods and services these systems produce.

In Pakistan, the impact of climate change has only been studied on main annual cereal crops and almost nothing has been done on perennial grasses and trees which are an integral part of the silvopastoral systems. This is a great challenge to planners, policy makers and researchers to long duration of the perennials and difficulties in changing varieties over short periods pose special challenges and more research is required to address the same. A thorough understanding of how well the perennial trees overcome the impacts of climate change is an essential requirement before promoting their use.

A detailed survey of the existing agroforestry systems may be carried out investigate the interaction among component species, classification of the trees used, and then redefinition of the systems in view of soil conditions, climatic conditions and socio-economic limitations. Detailed studies on the competition and complementarity between trees and crops for sunlight, space and soil recycling of nutrients are needed to be explored. Screening of trees for light, heat along with screening of crops which can tolerate and high relatively humidity. In future more emphasis should be given on pest and disease control and allelopathy may be studied in detail studied. Lastly there is a need study the socio-economic constraints and short-term and long-term benefits of farmers may be ensured.

8. Sri Lanka

Sri Lanka as an island has a total land extent of 6.5 million hectare and a population of about 23 million people. It has a great diversity in ecology and therefore a natural resource base for growing wide range of crops with contrasting qualities. Under the great ecological diversity in the country, three major agricultural sectors namely plantation, export agriculture and food crops have been evolved and consequently many agro-forestry systems have also been established in those agricultural sectors.

The climate of the country could be characterized as tropical and it has been significantly affected by recent changes. As a result, timely changes in technologies in agriculture have been put into action in order to successfully face the recent climatic changes. This paper discusses major agro-forestry systems in the country and their classification, associations and interactions in different components in agro-forestry, features of recent climatic changes in the country, agro-forestry technologies released for general use, recent climate smart technological advancements and strategic approaches in this regards.

The land in the country has been used for wide range of agricultural and non-agricultural uses. It also shows the land use changes since 1956. The extent of agricultural land has increased from 45 % in 1956 to 60 % in 2007 while land extent under various forest types has decreased from 44 % to 28.8 % during the period

The homestead lands are the home gardens where many tree crops are grown. The sparsely used croplands are the lands where the agricultural crops are grown but not properly managed and maintained. The sparsely used crop lands have been increased during this period indicating poor management of agricultural lands in the country.

Depending on the total annual rainfall, the island has been divided into 3 major climatic zones namely Wet, Intermediate and Dry zones (Panabokke, 1996). The Wet zone is the area which receives mean annual rainfall of above 2,500 mm. The Intermediate zone receives mean annual rainfall of 1,750 to 2,500 mm. The mean annual rainfall of the Dry zone is below 1,750 mm.

Increases in extreme events of rainfall, temperature and sea water level are some of most significant effects of recent climatic changes. In most locations in Sri Lanka, annual rainfall has shown neither significant increasing nor decreasing trend in the face of recent climatic changes in the country. However, variability of annual and seasonal rainfall has increased during recent decades especially with respect to Northeast monsoon which is the source of water for the major cultivation season (Maha) in the country. Increased occurrence of extremely rainfall events due to recent climatic changes has resulted frequent droughts and

floods. Being a tropical island with uniformly high temperature regime, most of seasonal crops in farming systems inclusive of agro-forestry systems in Sri Lanka operate near maximum of the optimum temperature range of respective crops. Thus crop injuries due to high temperature are inevitable particularly in seasonal crops in agro-forestry systems in the country under increased temperature. As an island, Sri Lanka is highly vulnerable to increases in sea water level with varying degrees of sectoral impacts. It is highly probable that sea water intrusion to agricultural lands is vulnerable as a result of the changing climate which will lead to further reduction of land available for agriculture. Increased sea water level will also exacerbate coastal erosion in affecting coconut, low country tea and cinnamon plantations in the country.

The agroforestry system in Sri Lanka is critical for the farming communities. Nine major agro-forestry systems have been identified in Sri Lanka. Most of such agro-forestry systems have been confined to Wet and Intermediate zones. Greater total annual rainfall (above 2,500 mm in the Wet zone and 1,750 to 2,500 mm in the Intermediate zone) and better distribution of rainfall in the year in the wet and Intermediate zones support for occurrence of wide range of tree species and thereby emerging many agro-forestry systems in the above climatic zones. Only one agro-forestry system, alley cropping based seasonal croplands, has been emerged in the Dry zone which is still at early stages of development.

- **Tea plantations** (*Camellia sinensis*) has occupied a land extent of 189,800 ha as plantations and small holdings (LUPPD, 2007) and provides black tea for income from export and local consumption. This agro-forestry system has been confined to low, mid and up country in the wet and intermediate zones in the country. In addition to tea, some shade trees such as *Grevillea robusta* (Silver Oak), *Albizia moluccana*, *Acacia decurrens* (Black wattle), *Erythrina lithosperma* (dadap), *Gliricidia maculata* are grown in this agro-forestry system (Kathiravetpillai, 1990). The shade trees additionally provide green manure, soil moisture conservation, minimizing sun scorch in pruned branches of tea, windbreaks, fire wood and timber.
- **Rubber plantations** (*Hevea brasiliensis*) has occupied a land extent of 183,200 ha as plantations and small holdings (LUPPD, 2007). In most cases, it is grown as a mono crop but in some older plantations, it is intercrop with some other tree crops such as cocoa. Space in between trees is occupied by an undergrowth or live mulch which is in most cases *Pueraria phaseoloides*, *Mucuna bracteata* or grasses. Rubber plantations not only provide a canopy which reduces the impact of sun as well as the atmospheric warming but they root deeper and therefore remove less amount of soil water per unit land area (Samarappuli, 2010). Hence, commercially grown rubber plantations can be considered as an alternative to a forest system, which is sustainable,

conveniently renewable and compatible with nature and that provide economic benefits.

- **Coconut plantations** (*Cocos nucifera*) has occupied a land extent of 313,700 ha as plantations and small holdings (LUPPD, 2007) and provides various products such as nut, oil and timber for income from export and local consumption. The majority of coconut plantations, particularly small holdings, have been maintained as monocultures. Coconut based agro-forestry (inter cropping, mixed cropping, multiple cropping, alley cropping and mixed farming) research were undertaken for optimum utilization of resources, thereby increasing the productivity and returns from the land. In case of mixed cropping, Gunathilake and Liyanage (1995) reported that cocoa (*Theobroma cacao*), coffee (*Coffea canephora*), pepper (*Piper nigrum*), cinnamon (*Cinnamomum verum*), clove (*Eugenia caryophyllus*), nutmeg (*Myristica fragrans*), ranbutan (*Nephelium lappaceum*), mulberry (*Morus alba morus*), lemonine (*Citrus spp*) and vanilla (*Vanilla planifolia*) performed better in the wet zone in the country and cashew (*Anacardium occidentale*), mango (*Mangifera indica*) and lime (*Citrus acida*) in the intermediate zone.
- **Cinnamon plantations** (*Cinnamomum zeylanicum*) is of great economic and social importance as a spice crop. Sri Lanka is the world largest producer and exporter of “true cinnamon” contributing more than 90 % of the share to the world’s true cinnamon trade. This agro-forestry system has been confined to low country wet zone in the country and it exists as plantations and small holdings.
- **Mixed perennial** have agro-forestry system have main crops of mixed perennial croplands include pepper (*Piper nigrum*), coffee (*Coffea sp.*), cocoa (*Theobroma cacao*), clove (*Eugenia carophyllata*) and nutmeg (*Myristica fragrans*) and the space between trees is occupied by grasses as an undergrowth or live mulch. In addition, leaf litter will also serves as dead mulch. **Kandyan forest gardens** (KFGs) have been a dominant form of traditional agro-forestry system for centuries, particularly in mid country wet zone in the country. The homesteads in Sri Lanka have occupied a land extent of 1,028,600 (LUPPD, 2007) of which a major portion exists as KFGs. It provides spices, fruits, beverages, condiments, vegetable, flowers, medicinal herbs, fire wood, timber for food and income as well as cool and pleasant living environment for rural communities in the region. On an average, the KFGs are one-third of a hectare in size with over 250 individual woody perennials of about 30 species (NARESA, 1991). Studies related to hydrology (Gunawardena et al., 1994), soil fertility (Kendaragama and Jayasundara, 2012), cash crops (Jacob and Alies, 1987), household income (Kendaragama,

1983), shared gender leadership (Kendaragama and Pathirana, 2011) and alternatives for the system (Gunaratne, 2001) have highlighted some physical, biological, economic and social aspects of this agro-forestry system. Major tree species in this agro-forestry system include coconut (*Cocos nucifera*), king coconut (*Cocos* sp.), areca nut (*Areca catechu*), pepper (*Piper nigrum*), coffee (*Coffea* sp.), cocoa (*Theobroma cacao*), clove (*Eugenia carophyllata*), nutmeg (*Myristica fragrans*), jak fruit (*Artocarpus integrifolia*), Breadfruit (*Artocarpus altilis*), banana (*Musa sapientum*), mango (*Mangifera indica*), dhurian, avocado (*Persea Americana*) and papaw (*Carica papaya*). The space between trees is occupied by grasses as an undergrowth or live mulch. In addition, the leaf litter serves as dead mulch.

- **Sloping agricultural land technology (SALT)** based tea, Sloping agricultural land technology (SALT) based vegetable lands are also practiced in Sri Lanka. SALT based tea lands have been confined to rain-fed uplands in hilly terrain in the wet and intermediate zones in the country as a sub agro-forestry system evolved from tea plantations. Alley cropping based seasonal croplands are also practiced in the country.

Significant tree crop association exists in most of agro-forestry systems in Sri Lanka. Trees in above agro-forestry systems include crops and plants providing supporting services. Among the plants providing supporting services. As mentioned above in different agroforestry system practices in the country, purpose of growing tree is mainly for green manure for companion food crops, soil erosion control by placing tree lopping on contours, maintaining simulated forest condition by tree canopy management, soil moisture conservation by placing tree lopping as mulch, feeding domestic animals such as cattle and goat with green biomass of trees and fire wood from hard wood of tree lopping for domestic needs.

Significant competition for available phosphorus has been showed no other then in alley cropping (Handawela and Kendaragama, 1991; Seneviratne Banda et al., 1992) and Kandyan forest garden systems (Kendaragama and Jayasundara, 2012) in the country. Agro-forestry systems provide green biomass and it is used as fodder for feeding farm animals in establishing tree-crop-animal integration in farms.

Agro-forestry-environment linkages have also been effective in soil erosion in the same environment. Some of the benefits of practicing agro-forestry, alley cropping in particular, include suppression of grass type weeds in cultivation plots (Kendaragama, 1995), improvements in soil tillage, improvements in soil microbial populations (Rajapaksha et al., 1993), improvement in soil physical and

chemical properties (Handawela and Kendaragama, 1991; Gunasena et. al., 1991) and creation of comfort micro climate for farm workers. Technological advancements in the nine identified agro-forestry systems related to climate smart agriculture are discussed below.

Minimum land preparation has been practiced for crop cultivation in most of agro-forestry systems in Sri Lanka as an energy smart technology. It helps maintaining soil carbon stocks and thereby contributing towards mitigating climate change effects. Practice of mulching has been a common technology to all agro-forestry systems in Sri Lanka as nutrient smart technology (table 4). The mulching materials include fallen tree leaves as dead mulch, creeping types legumes such as *Mucuna* species, rice straw brought from paddy fields, live mulch with grasses and lopped tree hedgerow biomass. Some of the promising runoff water harvesting technologies developed in the country includes lock and spill drains, water percolation pits and farm ponds. These technologies have not been recommended for lands having a threat of occurring landslides, earth slips and other forms of mass movements in soil.

The Lock and spill drains have been developed for lands having even surfaces and a considerable soil depth. This technology has been well taken by some plantations (tea, coconut, and cinnamon), mixed perennial croplands and Kandyan forest gardens. Water percolation pits have been developed for lands having uneven surfaces and a considerable soil depth. The farm ponds have been developed for lands having considerable soil depth and natural surface depressions. Contour hedgerow technology is usually adopted in the form of double hedgerow in SALT and single hedgerow in alley cropping. Trees on contours help not only controlling soil erosion but also improving soil fertility. Hence, these technologies are more suitable for lands degraded by both soil erosion and declining soil fertility.

Expansion of extents in saline and sodic soils in farming systems, occurrence of frequent droughts and subsequent floods, sea water intrusion and raising temperature have been identified some adverse effects of farming lands related to recent climatic changes. Crop and variety screening programs are in progress in the country in order to release crops and varieties tolerant to above stress situations. In addition, water barriers have been adopted to control sea water intrusion into some farming systems in the coastal area in the Southwestern region.

Organic input use in place of chemical fertilizer and pesticides has been an emerging strategy for ensuring quality of crop harvest and thereby obtaining better prices for crop produce in many recently evolved agro-enterprises in the country. Such enterprises have also been diffused to many agro-forestry systems such as plantations (tea, coconut and cinnamon), Kandyan forest gardens and mixed perennial crop lands. This kind of enterprises encourage organic material

addition to farm lands, indirectly helps maintaining soil carbon stocks and reducing carbon release to the atmosphere.

OK technology is very popular and is vegetable cultivation in Kandian forest gardens has been diminished in past 4 decades due to severe damages from small wild animals such as wild boar, porcupine and rabbit. Interaction between trees and herbs like vegetable for water, sun light and other growth resources aggravated the above problem. Hence, a technology called “OK technology” has been developed in 2007 and promoted since then in order to enhance vegetable production in the forest garden system. The OK (Over Knee) technology means cultivation of herbaceous vegetable using a soil based growth media placed in individual pots and mounted on a steel structure. This technology has been accepted by the forest garden communities but the diffusion of the technology within the garden system has been restricted by the high cost involved (US \$ 75) in the construction of the metal structure of the technology. It suggests the need of a financial concession at the early stages in the promotion of this technology.

Agro-forestry potential as CSA technology

As climate smart agriculture technologies is because the tree component has an ability develop simulated forest condition in the crop growing environment and thereby controlling increases in ambient temperature particularly during day time. Continuous addition of organic matter in the form of tree lopping, weed biomass, crop residues, live mulch, dead mulch and leaf litter to soil helps maintaining soil organic matter status. Practice of no tillage or minimum tillage in crop cultivation helps maintaining carbon stocks in soil in reducing carbon emission to the atmosphere. Hence, agro-forestry can be considered potential systems for climate smart agriculture.

Constraints to up scaling agro-forestry sector in Sri Lanka exist in many directions and some of the considerable constraints are discussed below:

At present in Sri Lanka, many government institutions are involved in agro-forestry sector. The institutions include Department of Agriculture, Provincial Department of Agriculture, Department of Export Agriculture, Department of Animal Production and Health, Tea Research Institute, Rubber Research Institute, Coconut Research Institute, Forest Department, Mahaweli Authority of Sri Lanka, Hadabima Authority of Sri Lanka, Land Use Policy Planning Department and Agricultural Universities. Many private sector organizations and non government organizations are also involved particularly in expansion of agro-forestry sector in the country. Therefore, an institutional integration is needed to improve agro-forestry sector. Further, it is suggested to develop a master plan for agro-forestry sector.

Strengthening gap filling research, training on new technologies and adoption of effective extension methodologies related to agro-forestry has a significant potential for scaling up of this technology. In many agro-forestry systems such as alley cropping, SALT, mixed perennial croplands and coconut plantations, the tree component, *Gliricidia sepium* in most cases, does not provide any significant economic returns for farmers. It has restricted the expansion of such agro-forestry systems among farming communities. Research is needed to find out tree species which provides economic returns also for farmers in addition to other services to the particular agro-forestry system.

Gliricidia sepium has been used as the tree component in many agro-forestry systems such as alley cropping, SALT in vegetable, mixed perennial crop lands, Kandyan forest gardens and tea plantations. The vegetative growth of *Gliricidia sepium* exists at an inadequate level at higher elevations particularly above 300 meter above sea level.

Potentials for improvement of agro-forestry sector in Sri Lanka exists in many directions and some of the significant potentials are discussed below. Some sub sectors in agro-forestry have not been fully exploited in Sri Lanka. The sub sectors include silvi-pasture, silvo-fishery and other potentials such as application of agro forestry technology in water management, salinity management and land reclamation. Above sub sectors needs fully exploitation in Sri Lankan agriculture.

Acceleration of processes such as deforestation, degradation exploited lands, loss of bio diversity and climate change has been significant environmental issue in Sri Lanka. Expansion of agro-forestry helps mitigate or reverse above processes.

Sri Lanka has 3 major climatic zones namely Wet, Intermediate and Dry zones. Tree crop based farming systems have been mainly confined to wet and intermediate zones in the country due to adequate distribution of rainfall in the year. As a result, most of agro-forestry systems have also been evolved in above climatic zones and the systems include major 4 plantation systems (tea, rubber, coconut and cinnamon), mixed perennial croplands, Kandyan forest gardens and SALT based tea and vegetable lands and alley cropping based seasonal croplands.

The climate smart agriculture technologies adopted in above agro-forestry systems include minimum land preparation, mulching, water harvesting technologies, contour hedgerows (SALT and alley cropping and multi-functional contour bunds), stress tolerant crops and crop varieties, sea water barriers, organic input based agro-enterprises and the OK technology. The potentials of agro-forestry systems for promotion of climate smart agriculture include development of simulated forest conditions for companion crops; continuous addition of organic materials to soil in the form of leaf litter, tree lopping, weed biomass and crop residues; and practice of no tillage or minimum tillage.

Lack in institutional integration; strengthening gap filling research, training on new technologies and adoption of effective extension methodologies; significant economic returns from most of tree species being used in agro-forestry systems in the country; and suitable tree species for higher elevations in the country have been major constraints for promotion of agro-forestry in the country.

Some sub sectors in agro-forestry which have not been fully exploited in country can be considered as potentials for improving agro-forestry sector in Sri Lanka. The country has taken necessary steps to promote above climate smart technologies in order to satisfactorily face for recent climatic changes and their future developments on existing farming systems and to ensure dietary, economic, social and environmental services of such farming systems.

Chapter 2

Technological advancement in agro-forestry systems: strategy for climate smart agricultural technologies in SAARC countries in Afghanistan

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Abstract

Afghanistan's natural resources (forests and pasture) due to the previous policies are under pressure and unsustainably used by local people and have been changed to agriculture and residential areas that led the forests degradation. To end this adversity it is needed to change the previous policies and develop them according to the need of the time, due to this fact NR General Directorate of Ministry of Agriculture, Irrigation and Livestock has already begun the development of such policies, strategies and laws (using social and participatory methods). If through using these policies public, private sector and international organization collaboration maybe certain, all problems will be solved,

Natural Resources will expand and people livelihoods will get better. Fortunately, Afghan Nation has known the value of NR, using such opportunity the General Directorate of NR (MAIL) has been implementing CBNRM projects countrywide since 2006.

Introduction

Afghanistan is a landlocked country in south and central Asia, with a population of about (27) million, it has area of (652000) km², making it the 42nd most population and 41st largest nation in the world. It is bordered by Pakistan in the south and east, Iran in the west, Turkmenistan, Uzbekistan and Tajikistan in the north, and China in the northeast.

Afghanistan has an arid and semi – arid continental climate with cold winters and hot summers. The climate varies substantially from one region to another due to dramatic changes in topography. The wet season generally runs from winter through early spring, but country on the whole is dry, falling within the desert or desert steppe climate classification.

Degradation of environment quality and loss of resources presents one of the big challenges in the development of Afghanistan. Between (1990- 2000) Afghanistan lost an average of (29400) hectares of forest per year, to an average annual

deforestation rate of (2.25 %) which further increased to (2.92 %) per annum between (2000-2005). Forest now occupies less than (2 %) of country's total area. Rangelands are being converted to rain-fed wheat production which is highly effected climate.

Forest, Rangeland and Biodiversity

Afghanistan is geographically and ecologically diverse with four broad eco-regions, namely, temperate coniferous forests in the east, temperate grasslands and shrub-lands, Savannas and shrub-lands with minor occurrence in the northern region, grasslands and shrub-lands in the northern, southern and western parts of the mountainous regions and deserts and xeric shrub-lands in the southwest (UNEP 2008: Biodiversity profile of Afghanistan)

A few centuries ago deciduous and evergreen forests covered (5 %) of Afghanistan's current land area, including one million hectares of oak and two million hectares of pine and cedar growing mostly in the eastern part of the country. Open woodland dominated by pistachios, almonds and junipers occupied a third of the land areas. Today most of the original forests have gone. By the middle of 20th century, the total forest cover of Afghanistan was estimated at (3.1 – 3.4) million hectares. Forests now occupy less than (1.0-1.3) million hectares (2 % of country's total area), (SOE 2008).

The largest areas of forest are located in the eastern provinces, at present the forests occupy (1.7) million hectares and rangelands occupy about (30) million hectares, representing roughly 45% of the country's territory.

Forests in Afghanistan

Today most of the original forests have disappeared and destroyed during the decades of conflict. Forests now occupy 1.7 million hectares, or just two percent of the county's area, adding to the burden on the large portion of the Afghan population that depends on timber for construction and fuel for cooking and heating, and on the general economy which has lost a potential resource.

Afghanistan's once-productive pistachio forests almost disappeared in just three decades. For example, in the 1970s, in the provinces of northern Afghanistan were covered with productive pistachio forests and earned substantial revenue from the sale of nuts. These forests were almost lost in just three decades. In addition to providing for basic cooking, heating and construction needs, forests today are depleted by illegal logging. Unfortunately, as a result of rapid growth and skyrocketing global population, indiscriminate use of inaccurate and irresponsible due to the lack of awareness from the value of natural resources, lack of expertise in the management and operation of a number of rapidly declining natural resources, environmental depredated, air, water and soil are

more polluted, caused unbalance Ecology, warm climate and the process of greater intensity has chosen field.

Agroforestry

About 79 % of the Afghan population relies on wood for fuel, construction, Timbers which provided from natural forests and affected natural forests very badly. Therefore, one of the ways to conserve and protect the natural forests is implementing the agro forestry programs countrywide.

Forest Directorate in order to conserve and reduce the pressure on natural forests caused by illegal cutting, has started Agro forestry in 17 provinces through 360 forests associations since 2013. The main objective of this program is to reduce the pressure caused by illegal cutting on forests through providing people income resources and fuel wood. Due to this fact this department distributed 4000 rapid growth seedlings to be planted in about 0.5 hectare lands by each forest association. The implementation methodology of this program is as; people grow these seedlings next to their agriculture land and for the first year they are irrigated and maintained by the government and then based on Forest management law the maintenance and utilization of its resources will belong to the local people for the coming years. Using this way Forest Directorate got able to afforest above 1 hectare land in 17 provinces of the country. Following this program 800000 pistachio, Pine (Jalghoza), *Amygdalis communis* (Badam Kohi) seedlings have been distributed in the above mentioned provinces for 200 forest associations to plant them next to their agriculture land. It is worth to mention that the provision expenses, transporting and plantation of the mentioned seedlings were the responsibility of the government and future protection, maintenance, irrigation and exploitation belong to the local people.

This year it is planned to afforest almost 0.5 hectare land in 6 provinces of the country. As a result, the above mentioned agro forestry program has satisfied the government as well as the local people and forest associations. They are happy for it and demanded the extension of this program.

Agroforestry

Agroforestry is an integrated system of rural land resource management based on combining shrubs and trees with crops and /or livestock .whose interactions generate economic environmental and social benefits. A variety of agro forestry systems are used around the world and they can be classified in a number of different ways depending of the criteria employed for example .one classification approach is based on the type of components involved: salvo pastoral system (production of livestock and woody plant species). Agrosalvo cultural systems (woody plant species and seasonal plants) and agro salvo pastoral systems

(production of livestock, woody plant species and seasonal plants). Here with the key services of agro forestry are discussed as:

Economic services including the following:

- Diversification of economic activities.
- Diversification of agriculture revenues.
- Increase in yield from conventional agricultural systems.
- Reclamation of fragile or marginal lands

Environmental services include:

- Increase in plant and animal biodiversity.
- Decrease in wind and water erosion.
- Improvement in soil fertility.
- Improvement in soil hydrology regimes.
- Mitigation of air sound and outdoor r pollution.
- Water treatment.
- Carbon sequestration and storage.
- Reduction in deforestation.
- Improvement in microclimates.
- Mitigation of climate change impacts on agriculture.

Social services include:

- Job creation
- Food security
- Landscape enhancement
- Improvement in public opinion regarding agricultural and forestry activities

Land use services include:

- Diversified land use
- Use of marginal lands (abandoned agricultural land hill slope plots . etc

Cultural services including:

Use of local and indigenous knowledge Agro-forestry, which offers practical applications supporting the concept of sustainable development, is a concrete tool for harnessing the multiple functions of agriculture, agro-forestry practices can help to give a human face to landscapes in rural regions. And they are an important part of the multi-resource approach to private forest management.

The idea of integrating multiple uses through agro-forestry is growing in popularity among regional economic development players, and agro-forestry practices are being incorporated into various land management and development projects, agro-forestry generates environmental goods and services that can support the creation of a network of small and medium –sized spin-off enterprises which will provide services to support producer`s operations as well as product harvesting, processing and marketing .

Government agricultural policies and programs often address economic and environmental functions sectoral, resulting in the parallel development of multiple components crop insurance reduction in environmental risks, soil conservation, biodiversity protection carbon sequestration etc, and agro-forestry on the other hand represents a powerful integration tool, a variety of objective can be attained simultaneously through the planned implementation of agro-forestry systems.

Poplar trees, planted in Afghanistan

Distribution of 1,120,000 seedlings and saplings of poplar to be planted in 174 hectares of private land in the provinces such as Parwan, Kapisa, Baghlan, Takhar, Samangan, Bamyan, Baikundi, Maidan Wardak, Ghazni and Logar.

Provision and distribution of 1312 packages of working Tool Boxes consist of Pickaxe, shovels, hand carts, mowers, sprinkler, buckets, blades, scissors and thread for farmers of above mentioned (10) provinces who planted poplar in their lands. An area of 72 ha will be extended for poplar plantation within the year of 2016-2018. Distribution of 478800 of poplar seedlings to the farmers, and provision and distribution of 360 package of working tools for farmers.

Characteristic of Agro forestry:

- The cycle or period of this system is more than one year
- Concentrate on utilization of forest trees, shrubs and forages
- Usage/ Exploitation of two or more than two plants (intercropping) and in minimum one of the crops should be Perennial and woody plant.

Advantages of Agro forestry:

1. Increasing the resources of soil, water, air, animals and human resources in agriculture field.
2. This system consists of two or more than two products.
3. Is more economical
4. Supporting the conservation of Natural Resources.
5. Control soil erosion

6. Decrease temperature degree in summer by providing shadow.
7. By using this method we will have the capability of producing several crops at one time.

Disadvantages of Agro forestry:

In general this method as other methods has its problems and disadvantages as below:

1. Contamination by microorganisms and insects.
2. Competition for light, water (moisture) and nutrients is more in this system.
3. Damage to food crops during the cutting and harvesting of trees.
4. Rapid propagation of trees may remove food crops and occupy more land.
5. This system needs more human resources.

Analyzing and evaluation of the current situation of Afghanistan's natural resources

1. Afghanistan's agricultural sector is the largest manufacturing sector in the country, which is more than 85 percent of Afghans to sustain their livelihoods depend on it, and also has a major contribution to national economic growth, The agricultural sector has almost 7.9 million hectares of arable land, approximately 34 million animals (including poultry) (FAO, 2003), 30 million hectares rangelands and 1.7 million hectares of natural forest and many types of wildlife. In the last 5 decades due to insufficient investments and poor technology transferring, agriculture and natural resources sectors are still operated traditionally which caused unsuitable utilization of markets and production capacities.
2. Prolonged wars and drought effects on natural resources and further forests have been cut as firewood or sold abroad and the remaining amount is to meet the needs of fuel by people inside and outside the region, or sold in region markets by traffickers. Orchards, vineyards and pistachio forests also suffer from similar adverse effects.

Challenges

- Poor management during the civil war.
- Illegal cutting of Timber Forest and smuggling.
- Lack of security in provinces.
- Lack of professional staff.
- Premature and non technical harvesting of Pistachio nuts.
- Inadequate up to date data or information on percentage or density of forests.

- Inadequate capacity for data collection and Processing.
- Poverty.
- Cutting of forests for fuel wood and construction.
- Converting forest land to rain fed land and settlement.
- Trees or plant disease.
- Forest fire

Opportunities

- Existing of forest Policy and strategy.
- Existing of forestry, Rangeland and wildlife conservation laws.
- Existing of forests, rangeland and protected are as national management plan.
- Existing of NR policy.
- Draft of projects implementation with associations.
- Existing of Community forestry regulation.
- Implementation of reforestation projects in 22 provinces of the country.
- Existing of forestry association's establishment regulation.
- Existing of 420 forestry associations countrywide.
- Supports of International counterparts.
- Existing of International donors. .
- Cooperation of local people in forest protection and rehabilitation
- Interests of country residence for greenery.
- Cooperation of line ministries and municipality for greenery and plantation.
- Interest of government high rank.

Recommendation

- A plan should be established for knowledge acquisition and dissemination. A network of demonstration sites should be set up for the various agro-forestry systems applicable to Afghanistan.
- Operational and strategic knowledge acquisition efforts should be developed. Interdisciplinary programs and training courses should be developed for professional and technical agro-forestry employees. Structured funding opportunities for agro-forestry development should be explored in the public and private sectors. A comprehensive strategy for agro-forestry should be developed under forest directorate of NRM.

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Chapter 3

Technological advancement in agro-forestry systems: strategy for climate smart agricultural technologies in Bangladesh

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Abstract

Bangladesh is one of the densely populated countries of the world with a population of over 150 million within a territory of 142,776 km². To fulfill the growing need of this overcrowded population, it is urgently necessary to think about a joint production system utilizing land resources to achieve food and nutrition security, to fulfill the demand of fuel wood and timber, and finally conserve biodiversity. Greater adoption of planned agroforestry systems in all possible space of the country lead to combat the challenges of livelihood improvement. It is imperative to focus the technological advancement of agroforestry and formulate research and development strategies under climate change induced vulnerabilities. This paper reviews the scenario of vulnerability of agriculture to climate change, research and development advancement in agroforestry, potentials for improvement, and constraints in Bangladesh which may help in identifying strategies and policy. It indicates that some strategies like strengthening comprehensive research and development program, an efficient coordination among all stakeholders, building the system from bottom up, organizational and institutional capacity building, strengthening marketing channel and institutional environment and appropriate policy intervention may give priority for sustainable development in technology generation and wide scale adoption of agroforestry in Bangladesh.

Introduction

Depletion of natural resources

The arable land is reducing rapidly across the world due to high population growth and establishment of new industries, houses and other infrastructures. In Bangladesh perspective, the situation is very worse due to high population density and shrinking natural resource base and enormous pressure on the natural resources of the country. The arable land is shrinking at the rate of 86,000

hectares every year (BBS, 2008). Bangladesh has only 8.16 million hectares of arable land is one of the most densely populated countries of the world struggling hard to feed her more than 150 million people. Due to rapid growth of population there is a tremendous pressure on the forest lands. A country needs 25% of forest land of its total area for ecological stability and sustainability (Bari and Rahim, 2009). Bangladesh is endowed with only 13.6% of unevenly distributed forests (BBS, 2008). About 7,300 ha of forest land has been lost due to transformation to agricultural land, aquaculture, homesteads and other purposes. Substantial depletion of forest resources has occurred in the last few decades, and now it is reduced to less than 0.02 ha person⁻¹, which is the one of the lowest ratios in the world (BBS, 2008). As a consequence of rapid economic growth through industrialization and agriculture, forests are continuously shrinking at an alarming rate. Mangrove forests are encroached for shrimp culture, which provides a quick economic return at the cost of deterioration of the complex and fragile coastal ecosystem. Hill forests are being cleared to meet the increasing demand. In addition, some serious natural problems like top-dying of sundri (*Heritiera fomes*) trees in the Sundarbans and dieback of sissoo (*Dalbergia sissoo*), and bamboo blight in village forests have also contributed to the depletion of forest resources. In general, the people have lack of awareness about forest and environment which contribute definitely a negative impact on forestry in Bangladesh. The overall poor socio-economic conditions of the people lead them to harvest or collect wood especially fuel-wood, mostly for cooking from the government reserved forest areas. In addition, natural calamities, pollution, etc., also contribute to depletion of forest resources. Climate change is a very important issue which needs to undertake appropriate measures to face the escalating issue.

Threatens food and nutrition security

The current food deficit is likely to be increased further with decreasing land:man ratio. Again, the fruit consumption in the country is only 35 g day⁻¹ capita⁻¹, against 85 g whereas in case of vegetables, 80 g against 200 g day⁻¹. Moreover, most of the people of the country cannot afford to buy vegetables or fruits due to its unavailability and high price. As a result there is 26% of the population are undernourished throughout the country (Internet source).

Possible coping measures

Under these alarming situations, agricultural production as well as forest resources must be increased by using modern or new techniques. Multistoried agroforestry system is one of them where incorporation of fruits, vegetables, spices and some medicinal plants in these systems can be effective and fruitful. There are about 20 million homesteads in the country which covers about 0.3 million hectares, Most of the vegetable produced in the country are coming from

these homesteads (BBS, 2008). Traditionally farmers grow different types of crops in association with trees in their homesteads, where productivity of crops is low due to inadequate knowledge about the appropriate combinations and management techniques (Bari and Rahim, 2009).. From time immemorial, a large number of diversified tree species are grown in the homesteads and recently many exotic species are included. Besides homesteads and adjacent land, one-eighth of the land surface area of Bangladesh consists of hills and valleys that also offer potentials for year round fruits, vegetable and forest trees production under Multistoried Agroforestry systems.

A holistic approach of agroforestry systems can be of great significance in this regard by:

- Integrating appropriate species of woody perennials on farmlands along with other components of the farming system not in a competitive but in a complementary way;
- Integrating herbaceous crops and livestock on forest land according to the agroforestry management schemes so as to facilitate simultaneous production of wood and food crops; and
- Employing agroforestry techniques for reclamation of degraded lands and proper utilization of "wastelands".

Integration of appropriate fruit and fuel wood species on crop land, homestead and livestock production units thus seems to be one of the best strategies for mitigation of livelihood requirements in the rural areas of the country. Research on forestry activities are to be strengthened through undertaking need-based priority research and development where the primary responsibility goes to the Bangladesh Forest Research Institute (BFRI) in generation of demand-driven technology. The role of universities in Bangladesh cannot be ignored as they also conduct some basic research and dissemination of technology by Department of Forest (DoF) should be strengthened.

The Bangladesh Agricultural Research Council (BARC) has identified new potential arena of agroforestry research and implemented substantial research and development at cropland, homestead, hill, coastal and wastelands under different ecosystem through its coordinated national research institutes, universities, extension agencies and NGOs. In view of the development of agroforestry systems, it is therefore logical to document the technological advancement in agroforestry practices and assess its relevance as climate smart technologies.

Agriculture and climate change

Agriculture is the backbone of the country and is synonymous to the food security. Apart from food security, the sector alone contributes about 12% of the

GDP and employ 44% workforce of the country. Agriculture sector is directly related to the poverty of the rural poor people who account for majority of the population. As such, agriculture sector is one of the major contributors of income and employment generation in Bangladesh (Planning Commission, 2009).

Bangladesh is one of the most climate vulnerable countries in the world. Located between the Himalayas and the Bay of Bengal, the country is very prone to natural disasters (World Bank, 2010). Climate change accelerated the intensity and frequency of occurrences of salinity, storms, drought, irregular rainfall, high temperature, flash floods, etc. that resulted from global warming. Global warming is harmful for crops of the tropical countries (UNEP, 2009).

Impacts of climate change on agriculture

Ministry of Environment and Forests (MoEF) of Bangladesh reported the consequence of climate change on agriculture for better understanding of the coping strategies. Agriculture is the most vulnerable sector as its productivity totally depends on climatic factors like temperature, rainfall, light intensity, radiation and sunshine duration, which are predicted to be erratic. Incidences of floods, droughts, high temperature, flash floods and floods, etc., are predicted to be more frequent and intense. Salinity intrusion could be more acute problem in future due to sea level rise.

Impact of Temperature on Crop Production

Every crop has a temperature regime for their vegetative and reproductive growth. When temperature falls below the range or exceeded the upper limit then crop production faces constraints. A study (Islam et. al., 2008) found that 1⁰C increase in maximum temperature at vegetative, reproductive and ripening stages there was a decrease in Aman rice production by 2.94, 53.06 and 17.28 tons respectively. With the change in temperature (by 2⁰C and 4⁰C), the prospect of growing wheat and potato would be severely impaired. As a result loss may exceed 60% of the achievable yields (Karim, 1993). Higher temperature has negative effect on soil organic matter also.

Impact of Rainfall on Crop Production of Bangladesh

Rainfall is one of the major climatic factors for crop production. All crops have critical stages when it needs water for their growth and development. Moreover excessive rainfall may occur flooding and water logging condition that also lead to crop loss. Scarcity of water limits crop production while irrigation coverage is only 56% as delivered by the Bangladesh Agriculture Development Corporation (BADC). It was found that 1mm increase in rainfall at vegetative, reproductive and ripening stages decreased Aman rice production by 0.036, 0.230 and 0.292 ton respectively (Islam et. al., 2008).

Impact of Sea Level Rise on Crop Production

Sea level rise affects agriculture in three ways, i.e., by salinity intrusion, by flooding and by increasing cyclone frequency and its depth of damage. Combined effects of these factors decrease agriculture production in the coastal zone. Salinity intrusion due to sea level rise will decrease agricultural production by unavailability of fresh water and soil degradation.

Salinity also decreases the terminative energy and germination rate of some plants (Rashid et. al, 2004; Ashraf et. el., 2002). The loss of rice production in a village of Satkhira district was investigated and found in 2003 was 1,151 metric tons less than the year 1985, corresponding to a loss of 69%. Out of the total decreased production, 77% was due to conversion of rice field into shrimp pond and 23% yield loss.

Sea level rise cause inundation of more area where about 1/3 of Bangladesh or 49,000 sq. km. area are influenced by tides in the Bay of Bengal. In a study by Butzengeiger and Horstmann, (2004) found that if sea level rise up to 1 meter, normal flood waves can be expected to increase from presently 7.4 meters to 9.1 meters. In Bangladesh about 15-17 million people will be displaced from the land inundation by sea level rise which will cost 12-16% of total land area (World Bank, 2000).

Impact of Flood on Crop Production

Flood has most deleterious effect on crop production of Bangladesh. The 1988 flood caused reduction of agricultural production by 45% (Karim et. al, 1996). Higher discharge and low drainage capacity, in combination with increased backwater effects, would increase the frequency of such devastating floods under climate change scenarios. Prolonged floods would tend to delay Aman plantation, resulting in significant loss of potential Aman production, as observed during the floods of 1998. Loss of Boro rice crop from flash floods has become a regular phenomenon in the haor areas over the recent years. Considering all the direct and induced adverse effects of climate change on agriculture, one may conclude that crop agriculture would be even more vulnerable in Bangladesh in warmer world (World Bank, 2000).

Impact of Cyclone on Crop Production

Cyclone cause huge damage to production of crop. FAO/GIEWS Global Watch (2007) reported that cyclone SIDR, affected aman rice crop production at the time of harvest by about 70% of the annual production. According to Department of Agricultural Extension (DAE) the loss in rice equivalent to 1.23 million tonnes, with 535,707 tonnes in the four severely affected districts, 555,997 tonnes in

badly affected 9 districts and 203,600 tonnes in moderately affected (Source: internet) districts in Bangladesh.

Impact of Drought on Crop Production Due to Climate Change

Drought mostly affects Bangladesh in pre-monsoon and post-monsoon periods. During the last 50 years, Bangladesh suffered about 20 drought conditions. During 1981 and 1982 droughts affected the production of the monsoon crops only. The drought condition in north-western Bangladesh in recent decades had led to a shortfall of rice production of 3.5 million tons in the 1990s. If losses, to other crops (all rabi crops, Sugarcane, Tobacco, Wheat etc.) as well as to perennial agricultural resources, such as, bamboo, betel nut, fruits like Litchi, Mango, Jackfruit, Banana etc. are considered, the loss will be substantially much higher (Source: internet).

Resultant impact and economic losses

Natural calamities intensified by climate change, damage field crops in every year. In 1990's, drought in the north western Bangladesh caused a shortfall of rice production by 3.5 million tones. Unprecedented flash flood in the haor areas had accounted for a loss of about 150,000 metric tonnes of rice at the beginning of 2010. It has been reported (Karim and Iqbal, 2001) that salinity affected areas in coastal Bangladesh have increased from 0.83 million hectares in 1990 to 3.05 hectares in 2001. Another study estimated that in eastern Bangladesh alone 14,000 tons of grain production would be lost to sea level rise in 2030 and 252,000 tons would be lost by 2075 (current agricultural production for the country is 30 million tons). OECD referred to a study that estimated a GDP decrease in the range of 28% to 57% from 1m sea level rise (OECD, 2003).

Existing adaption mechanisms and constraints

Adaptations to climate change for agricultural sectors includes the resilient crop variety, cropping pattern, irrigation techniques, sustainable land management, early warning, research, subsidies, supply of inputs etc. The country is trying to develop coping mechanism against natural hazards like floods, droughts, tidal-surges etc. through support of the Government.

Research

Researchers of institutions under National Agricultural Research Systems (NARS) are engaged to innovate technologies that will be resilient to climate change and ensure expected crop production. Research and developments of stress (salt, submergence, drought, high temperature) tolerant rice and wheat varieties can ensure food security by an increase in yield of up to 20%. Bangladesh Rice Research Institute (BRRI) has released salt-tolerant rice varieties

like BR-11, BR-23, BRRI dhan-28, BRRI dhan-41, BRRI dhan-47, BRRI dhan-53 and BRRI rice-54 using gene-marker technologies. Innovations of short duration varieties like BRRI dhan-33 and Binadhan-7 by the BRRI and Bangladesh Institute of Nuclear Agriculture (BINA) is successfully cultivated to avert so called mona situation in the northern Bangladesh. BRRI dhan-32 and BRRI dhan-52 can stand submergence during flash flood. Bangladesh Agriculture Research Institute (BARI) is working with heat tolerant wheat and tomato varieties.

Irrigation

Irrigation will be crucial in the context of climate change. Introduction of 'Alternate Wetting and Drying (AWD)' irrigation technique has been found to be promising in increasing water use efficiency for crop production. In the comparatively dry Rajshahi and Rangpur division (Barind region), Barind Multipurpose Development Authority (BMDA) ensures irrigation for rice where 100 hour free electricity bill for irrigation of last year's aman season were provided to the farmers from the Ministry of Agriculture (MoA) in 2009. A 20% rebate in the electricity bills for irrigation throughout the country to encourage irrigated cropping has also been provided by the government. Both the BADC and BMDA are in pursuit of increasing irrigation coverage by taking newer projects and programmes in every year. To achieve food production, it was suggested that the target of 150,000 ha of land to be brought under irrigation by 2012 (Planning Commission, 2009).

Financial Adaptation

For the first time the government, apart from subsidies and rehabilitation, has given various incentives to farmers for crop production. Recently, financial assistance of around BDT 750 crore for diesel fuel used to irrigate boro rice was distributed among the farmers through their bank accounts. Farmers affected by the flash flood were given free seeds and fertilizers that cost BDT 48 crore for the boro season in 2011. To compensate the loss of boro rice by flash floods in haor areas, fertilizers worth BDT 26 crore were distributed free among 346,100 farmers for enhanced Aus production. Increased allocation for fertilizer subsidy, irrigation and other inputs and research activities are some notable financial contributions of the public sector. Such augmentation of support for enhanced production is a crucial adaptive measure for sustained production.

Interventions for smallholder farmers like storage facility to reduce post-harvest losses, increasing agro-processing facilities as well as promoting community mobilizations are important. In order to ensure fair market price of crop products, the MoA is going to establish 'Agri-business Cell' in the ministry. The Directorate of Agricultural Marketing (DAM) has started 15 retailers and 60

growers markets throughout the country to ensure fair price and to eliminate middleman ship in agricultural marketing.

Sustainable Land Management Practices

Land is the base for crop production. Soil resources of the country are experiencing pressure for increased food production. Increasing cropping intensity and mineralization of soil organic matter exhausts the soils capacity to support crops. Soil Resources Development Institution (SRDI) of the MoA is working to improve soil health (SRDI, 2010). The institute prepared Upazilla Land and Soil Resources Utilization Guide for 459 upazillas throughout the country that would help farmers to apply fertilizers according to the need based on fertility status of the soil. Moreover, MoA is working with the Ministry of Land to enact proposed Agricultural Land Conservation and Land Use Act, 2011 to safeguard agricultural lands from encroachments for developments.

Fertile soil is the prerequisite for better production. Organic manures can increase soil fertility and productivity. The MoA is encouraging farmers to use organic fertilizers like compost, farmyard manure to safeguard soil health. The farmers are advised to use green manure and bio fertilizers instead of chemical fertilizers to sustain soil health. Agronomic practices like intercropping with leguminous crops, reduced tillage, alternate cropping, soil mulching, etc. are applied by the farmers to maintain soil fertility. These actions would reduce the use of chemical fertilizers, thereby mitigate emissions from them.

Financing adaptation in agriculture

Finance and technology are the means to achieve adaptation and mitigation. After investment by the Bangladesh government in disaster preparedness and adopting other strategies for climate change, financing and implementing the strategies is the challenge for the moment (World Bank, 2010). National Adaptation Program of Action (NAPA) addresses immediate and urgent needs to deal with climate change. Climate change has propelled an initiative to develop a multi-donor trust fund contributed by the GoB and the development partners. Commitment was made in the Copenhagen Accord at COP-15 to establish 'Copenhagen Green Climate Fund' to aid projects design to mitigate greenhouse gases. The BCCSAP urged to allocate funds from international communities on grant basis. This would help to access to the technologies required for efficient mitigation. Bangladesh government established 'Climate Change Trust Fund' amounting to 100 million USD. This funding is already in use for the implementation of plans spelled out in the BCCSAP (MoEF, 2009). Climate change is in the agenda of the NARS institutions that are implementing various research projects funded by the development partners along with GoB.

Constraints in Assessing Financial Flows in the Agriculture Sector

The Climate Change Strategy and Action Plan (2009) confirmed that additional amount of allocation will be required for sustained adaptive measures. The Government of Bangladesh invested over 10 billion USD and adopts policies to combat climate change impacts. About 500 million USD is estimated to be needed to implement action plans of BCCSAP for first two years.

National and International Sources of Finance and Investments

The Green Climate Fund, established as a financial mechanism of the Copenhagen Accord predicts annual financing for developing countries rising to around \$100 billion per year by 2020, in support of developing countries to mitigate and adapt to climate change. In fact, in November 2010, Bangladesh became one of the first three countries to tap into a pilot climate change fund to help developing and highly vulnerable nations adapt to climate change. Part of this grant would help shore up the country's coastal embankment to withstand cyclones and storm surges, and also important for water supply projects and promote farming of more resilient crops. However, these types of funds need to be administered properly with sound disbursement modalities, an appropriate governance structure and careful resource management.

Policy and institutional arrangements

Climate change impacts are not unknown to the policy makers. The National Adaptation Program of Actions (NAPA) provides guidance for adaptation measures taken up to combat climate change impacts. The revised version of National Agriculture Policy of 2011 has included climate change as one of its three priority areas. The Agriculture Extension Policy of 1996 puts emphasis on sustainable agricultural however and explicit consideration extension of climate resilient variety or cropping pattern need incorporation. Similarly, the Integrated Pest Management Policy of 2002 need to provide guidance on climate change and disaster risk reduction issues. There is an implicit mentioning that the policy should increase self-reliance of farmers by promoting locally developed and crop management practices which eventually address adaptation to climate change. National Seed Policy needs to put priority on seed production which is likely to be affected by climate change.

Climate change impacts on Bangladesh are not a future issue. The country is affected by salinity, flood and flash floods, droughts, temperature variations, erratic rainfall etc. which result in crop losses. Despite the country has shown resilience to climate change. The target of rice production was increased and being subsequently achieved in the recent years. Price subsidy for fertilizer and other agricultural inputs has contributed to make them affordable to the farmers.

Research on stress tolerant technologies (seed, fertilizer, irrigation, agronomic practices) and their expansion act as positive adaptive action against climate change. Comprehensive and coordinated study on the real time impacts of climate change on crop production and assessment of the needs to avert the crisis must be carried out for making correct policy decision. Financial assistances for production and to compensate crop losses were channeled to the farmers in a comparatively transparent way through their bank accounts. Use of e-Agriculture through internet and village based AICCs allowed farmers to get instant expert opinion on problems of their crop fields. These ‘farmers-friendly’ actions encouraged farmers, who work hard to ensure better production in recent years. The MoA is committed to harness efforts ensure food security by taking all necessary steps. Allocation for subsidy of fertilizers and other assistances for desirable crop production share majority of the ministry’s financial budget. Funding is continued for research and development of stress resilient technologies by the fifteen affiliated departments of the MoA. Still the challenge of producing more food crops for increasing population from decreasing cultivable lands prevails for food security of the country.

Elevated pressure for food production may undermine or overlook the deleterious effects of using genetically modified (GM) materials and hybrid seeds that affects human health. Concepts of food safety and the use of GM technologies also deserve due attention as far as the health of the consumers are concerned. Crop production in recent years was able to accomplish the target. However, domestic crop production still supplemented with the import of rice, wheat and other crops to meet national food demand. Imports are augmented due to crop loss from uncertain climatic affects. Increasing price of foodstuffs and agricultural inputs like seeds, fertilizers, agrochemicals along with their unavailability in the international markets make the economy of Bangladesh more vulnerable.

Agroforestry systems in the country and their classification

Agroforestry practices are not new in Bangladesh. These were embedded in the traditional forest plantation activities by way of Taungya. Taungya system was first introduced in Burma. It was adopted in Bangladesh at Kapta in the early 1870. This system is a modified term of shifting cultivation in which labour is permitted to raise crop in an area but only side by side with the forest species planted by them. The practices consist of land preparation, tree planting, growing agricultural crop for 1 to 3 years until shade becomes the dense and then moving on to repeat the cycle in a different area. Some eminent foresters like Sir H. G. Champion, Willium Shilch and others visited the forest plantation and recommended adoption of Taungya system for plantation. Under the Tangya system, each laborer was given 5 bighas of farmland in exchange of 19 man-days of free labor a year. The Taungya laborers were also bound by an agreement to

work in the forest on daily payment basis in addition to 10 man-days of free labor. The system worked very well when the population of the Taungya laborers was small, and the price of timber was low. Unfortunately, the system was never institutionalized. When the population increased, people became poorer and the prices of forest products went up, they became victims of the greedy timber merchants and land grabbers. Thus the forest started disappearing. Its importance was appreciated when the energy crisis was felt and food and fodder crisis also appeared. Recently agroforestry practices have been reinforced by the need for socio-economic and environmental sustainability. Some common agroforestry systems are found in the country.

Agroforestry in Traditional Forest Plantation

In Bangladesh agroforestry has been practiced in various forest plantations. Agricultural crops including paddy, cotton, chilies, sesame, pigeon pea, mustard, maize, and different vegetables have been grown inside the plantations. In 1978-79, the area under agroforestry was 9098 acres where the number of families involved were 3121. The main vegetable crops grown were: cowpea, cucumber, brinjal, ladies finger and sweet guard and also grow maize, papaya and medicinal plants. So agroforestry offers high crop yield and employment opportunities.

Agroforestry in Encroached and Denuded Land

In Bangladesh large areas of government forest land have been encroached illegally. Moreover, large areas of the encroached forest land are lying denuded with soil erosion and other associated problems. These problems are more severe in the hill forests and in the Sal forests. In Dhaka, Tangail, Mymenshing, Dinajpur and Rangpur, considerable areas of encroached and denuded land have been recovered and put under productive agroforestry and block fuel wood plantation.

Cropland agroforestry

Cropland agroforestry combines the production of agricultural crops and trees in the cropland through intercropping.

a) Boundary plantation (hedge rows)

Boundary plantations combine perennial, preferably leguminous trees or shrubs, grown around an arable crop. During the cropping phase the trees are pruned and the pruning's used as green manure or mulch for the arable crop to improve the organic matter status of the soil and to provide nutrients, particularly nitrogen. Boundary plantations as windbreaks also protect crops. Commonly used trees are prickly acacia (*Acacia nilotica*), betel-nut (*Acacia catechu*), date palm, eucalyptus (*Eucalyptus brassiana*) and rose wood (*Dalbergia sissoo*). Eucalyptus and rose wood are fast growing trees with high timber values; prickly acacia, date palm and betel-nut also have high commercial values. Boundary plantations exert several benefits:

- Improved crop performance due to the addition of nutrients and organic matter to the soil/plant system;
- A reduction of the use of chemical fertilizers;
- An improvement in the physical nature of the soil environment;
- On sloping land, the tree rows act as a physical barrier to soil and water movement, resulting in significant reductions in erosion losses (Paningbatan et al. 1989); and
- The provision of additional products such as forage, firewood or stakes.

b) Alley cropping

This model is the most popular and is widely accepted in the study area. Multipurpose species – here, usually Mango (*Mangifera indica*) – trees are planted in rows. Paddy (*Oryza sativa*), wheat (*Triticum aestivum*), sugarcane (*Saccharum officinarum*), papaya (*Carica papaya*), banana (*Musa species*), ginger (*Zingiber officinale*), turmeric (*Curcuma domestica*) and different types of vegetables i.e., potato (*Solanum tuberosum*), bean (*Dolichos lablab*), datashak (*Amaranthus lividus*), lady's finger (*Abelmoschus esculentus*) are intercropped with the mango trees to provide a cash flow – particularly in the early years after the mangoes have been planted but have yet to yield. Paddy, wheat, sugarcane, papaya and banana are intercropped in the early years (first 12 years), and then the shade tolerant ginger, turmeric and vegetables are commonly planted later.

In some of the encroached and denuded lands, alley cropping mostly with 10 m x 1 m spacing in the north-south direction has been practiced in Sal forests. Because of irregular size of the plots given to the farmers, the alley sizes can not be strictly maintained. Some alternative arrangements have got to be found out to overcome these difficulties. Another very important factor pointed out by the farmers at Bannara is that they have no cattle to plough their land where they grow paddy. However, one NGO (Proshika), which has been assisting the Forest Department, has promised to give them cattle on credit. This appears to be a good association among the three groups i.e. Forest Department, the farmers and the NGO. It is expected that in future, this cooperation will further develop.

c) Strip plantation

Strip plantations are being practiced by the side of the national highways and embankments. To start with, strip plantation was practiced at Manikgonj by the side of the Dhaka-Aricha road with the help of local landless farmers. The crops raised were napier grass, papaya, lemon, date palm, jackfruit, koori, ipil-ipil, mahogany, sissoo etc. The plantation was established in 1981. At present fruit plants jackfruit and date palm started fruiting which results a good income generation for the farmers. Selection of crops depends on the socio-economic

need and environmental factors in the locality. The strip plantation should invariably be raised through participants, and a minimum period of one rotation usufructory right should be given to the participants for sustainable production.

Homestead Garden

There are about 20 million homesteads in the country which comprises about 0.3 million hectares of lands and most of the vegetables produced and consumed in the country are coming from these homesteads (BBS, 2008). These areas are also increasing due to construction of new houses for the ever increasing population. Planting trees near homesteads is a traditional land use system in Bangladesh. Homestead forests develop as small groves scattered around homesteads through ecological and anthropogenic selections (Alam and Masum, 2005). Traditionally farmers grow different types of crops in association with trees in their homesteads, where productivity of crops is low due to inadequate knowledge about the appropriate combinations and management techniques. From time immemorial, a large number of diversified tree species are grown in the homesteads and recently many exotic species are included. Multi-layered vertical stratification, species diversity, and diversity of economic plants rather than number of individuals per species are characteristic features of Bangladesh homestead forests. The homestead flora of Bangladesh ranges from annual herbs to woody perennials; including indigenous and exotic species of multiple uses (Khan and Alam, 1996).

Homestead agroforestry consisting of an assemblage of plants which includes trees, shrubs, and herbaceous plants, growing in or adjacent to a homestead or home compound, has a long tradition in the country. These are planted and maintained by members of the household with their products intended primarily for household consumption; they have considerable ornamental value and provide shade to people and animals.

Homestead agroforestry exemplify all the agroforestry characteristics of:

- an intimate mix of diversified agricultural crops and multipurpose trees fulfills most of the basic needs of the local population;
- the multi-storied configuration and high species diversity help reduce the environmental deterioration commonly associated with monocultural production systems;
- producing sustained yields in a resource-efficient way.

In spite of the very small average size of the management units, homestead agroforestry systems are characterized by high species diversity and usually 3–4 vertical canopy strata, which result in intimate plant associations. The layered canopy configurations and combination of compatible species are the most conspicuous characteristics of all systems. Contrary to the appearance of random

arrangement, the gardens are usually carefully structured systems with every component having a specific place and function.

All homestead agroforestry consist of an herbaceous ground layer, a tree layer at upper levels, and intermediate layers between. The lower layer can usually be partitioned into two, with the lowermost (less than 1 m height) dominated by different vegetable and medicinal plants, and the second layer (1–3 m height) being composed of food plants such as banana, papaya, yam, etc. Various fruit trees, some of which would continue to grow taller, dominate the intermediate layer of 3–10 m height. The upper tree layer consists of emergent, fully grown timber and fruit trees occupying the uppermost layer of over 25 m height, and medium-sized trees of 10–20 m occupying the next lower layer. Common trees of the upper stratum are: *Albizia procera*, *Aphanamixis polystachya*, *Artocarpus heterophyllus*, *A. lacucha*, *Polyalthia longifolia*, *Alstonia scholaris*, *Azadirachta indica*, *Dillenia indica*, *Mangifera indica*, *Cordia dichotoma*, *Elaeocarpus floribundus*, *Bombax ceiba*, *Syzygium cumini*; *Albizia saman*, *Swietenia macrophylla*, *Tamarindus indica*, *Toona ciliata*, *Acacia nilotica*, *Lagerstroemia speciosa*, *Ficus benghalensis*, *F. religiosa*, *F. racemosa*, *Anthocephalus chinensis*, *Eucalyptus camaldulensis*, *Areca catechu*, *Borassus flabellifer*, *Cocos nucifera*, *Gmelina arborea*, *Erythrina orientalis*, *Lannea coromandelica*, and *Litsea monopetala*. The mid stratum is dominated by medium-size trees, small trees, and bamboos. Common among them are *Holarrhena pubescence*, *Microcos paniculata*, *Citrus grandis*, *Ehretia serrata*, *Mallotus philippensis*, *Cassia fistula*, *Pithecello biumdulce*, and *Phoenix sylvestris*. *Bambusa balcooa*, *B. cacharensis*, *B. comillensis*, *B. nutans*, *B. salarkanii*, *B. tulda* and *B. vulgaris* are common bamboo species. *Adhatoda zeylanica*, *Cajanus cajan*, *Glycosmis arborea*, *Citrus* spp. *Duranta repens*, *Pithecellobiumdulce*, *Euphorbia antiquorum*, *Opumiadilleni*, *Sesbania* spp., *Lawsomia alba*, *Calotropis procera*, *Murraya* spp. and *Grewia* spp. are common shrubs. Many of them are of medicinal value and some of them are used as hedge plants. *Barringtonia acutangula*, *Crataeva magna*, *Erythrina fusca*, *Pongamia pinnata*, and *Trewia nudifolra* are common trees that grow along water edges in low-lying areas (Alam et al., 1991). *Calamus tenuis* is a common rattan palm of the villages.

Association and interactions

Tree-crop association (species grown)

In Bangladesh, vegetables and spices are often grown under the trees or using trees as trellis. The most common vegetables and spices grown in association with trees are aroids, stem amaranthus, Indian spinach, radish, brinjal, sweet gourd, bitter gourd, chilli and turmeric. Trees are also used as trellis to grow ribbed gourd, bitter gourd, sponge gourd, ash gourd, yam and country bean.

In the High Ganges River Floodplain the major crops grown with trees in highland crop fields in kharif season are direct-seeded upland rice, jute and aroids

(particularly mukhikachu) and in the rabi season lentil, mustard, chickpea and wheat (Chowdhury and Satter 1992). Mustard is frequently mixed with lentil or chickpea. Turmeric is common as a year-round crop, particularly in the fields where tree density is relatively high. The number of minor crops was higher than the number of major crops but the minor crops were grown by only few farmers. Banana, sugarcane, pineapple, and pigeon pea were found to be the minor year-round crops in highland. Occasionally, seedling nurseries were found in the fields planted with trees.

In medium highland transplanted aman rice is the only crop in the kharif season and boro rice, wheat, chickpea and linseed are the major crops in the rabi season. The minor crops are direct-seeded aus rice or jute in kharif and wheat, grasspea and sweet gourd in the rabi season. Information on the management of trees is rarely available. Farmers sometimes apply organic matter to fruit trees planted in the homesteads. Occasionally, some farmers also apply a little chemical fertilizers and water in the season to fruit trees like mango and litchi. In the crop fields farmers do not apply any manure or fertilizer specifically for the trees. Fallen leaves, crop residues and weeds removed from the crops are sometimes dumped at the base of the trees which eventually serve as manure.

Purpose of growing trees by different categories of farmers

Why do farmers grow trees? The reasons cover a wide range of uses and services derived from the trees which contribute toward meeting various needs of the families (Chowdhury and Satter 1992; Aktar et al. 1989). Farmers grow trees in homesteads for shade, beautification, protection against storm and vegetable products. On the other hand, they grow trees in the crop fields because crops can not be grown profitably due to poor fertility of soil, to get specific products like fruits, fodder, or juice of date palm, to earn cash to buy more land, to harvest additional products other than the crops, or simply they keep the trees which grew naturally (Table 3). Other reasons for growing trees were to generate cash for various purposes, to get fuel wood, timber and construction material, control soil erosion, and as insurance against risks of crop failure. Use of trees as living fence and for demarcation of plot boundary is also common. Some farmers are even aware of the contribution of the trees in keeping environmental balance. Farmers use trees and tree products in various ways. The relative importance of different species as multipurpose trees was calculated by multiplying the total score for different uses of a species by the percentage of farmers having the species. The major species based on their uses were, in order of importance, jackfruit, date palm, coconut, mango, bamboo, betel nut, babla, palmyra palm, sissoo and guava. Among them, jackfruit, date palm, mango and babla were used for more purposes than of the other species.

The relationship between farmers' stated purposes of growing trees, their reasons for felling them and the use of sale proceed derived from trees was studied by

Chowdhury and Satter (1992). It was found that only 14% of the farmers intended to generate cash from the trees but actually 46% felled trees for this purpose (Table 1).

Other activities like buying land, agricultural inputs and bullock, repaying loan, meeting day to day household expenditure and marriage costs accounted for about 24% farmers' cash expenses. Farmers often make a distinction between 'cash' and 'activities requiring cash'. The cash required for marriage of family members, buying land, agricultural inputs and bullocks, repaying loan and meeting day to day household expenditure were all considered by farmers as separate uses.

While only 15% of the farmers planted trees for fuel, actually 34% felled trees for this purpose, and although only 3% thought that they would use trees as construction material, much higher proportion of them (16%) did so. It is also interesting to note that about 8% of the farmers considered trees as insurance for meeting emergency needs but in practice 19% used the sale proceed to buy agricultural inputs, 2% to buy bullock, 15% to repay loan and 46% used it to meet day to day household expenditures all of which were perhaps done on emergency basis. Aktar et al. (1989) mentioned that farmers considered trees as a source of stable income and a means of risk management. Trees are also seen as savings and insurance (Evans 1988). Farmers considered trees as alternative source of food and cash in times of crop failure due to natural hazards like drought, flood etc. Poor farmers who do not have much land plant trees to create asset and alternative credit source for future generation.

Table 1. Relationship between some of the purposes of growing and felling trees, and the use of sale proceed from the trees by the farmers

Item	Mean response (%)		
	Purpose of growing	Purpose of felling	Use of sale proceed
Generate cash	14	46	8
Buying or leasing-in land	1	6	4
Cash for marriage	1	6	7
Buy agricultural inputs	0	2	19
Buy bullock	0	2	2
Repay loan	0	1	15
Meet daily expenditure	0	7	42
Fuel	15	34	0
Timber	4	2	0
Construction material	3	16	7
Furniture	0	14	4
Other purposes	86	21	6

Tree-crop interaction

Tree-crop interactions as perceived by the farmers have been described by Chowdhury and Salter (1992). Almost all the farmers (98%) thought that crop yields are reduced when trees are grown in the fields. However, up to certain age of the trees the reduction in crop yield is not probably significant. Farmers stated that mango did not reduce yield of crops up to about seven years, and jackfruit, babla, sissoo and mahogani up to about five years (Table 2). The case was reverse with date palm and palmyra palm. At the early stages of growth, palms develop thick covering canopies which do not allow much sunlight for the crops to grow well under their shade. These species caused yield reductions up to about 4.6 and 10.5 years, respectively. Later on, the plants grow erect and tall, and therefore, do not affect the growth of the crops underneath. However, the numbers of observations were a few except for babla and date palm and the information were generalized regardless of the crop species, varieties and growing season of the crops. It seems that the yield of mustard, chickpea, rice, jute and lentil are more severely affected when grown under the trees (Table 3). Their yields were reduced by 23-29% of that obtained in the fields without any trees. Rice grows vegetatively and develops more unfilled grains under the shade. Jute grows tall but the bark becomes very thin thus reducing the yield and quality of fibers. Other crops like wheat, aroids turmeric and potato can be grown with relatively good yields.

Looking at the standard deviations given in Table 2 and 3 it can be concluded that farmers fairly agreed about the age of trees up to which they do not significantly reduce crop yields but their observations on the yield reduction of crops varied widely as reflected by the large values of standard deviations. The effects of trees on the crops depend on many factors. The density, age and planting configuration of the tree species, management practices applied to the trees and the crops, growing season affect the tree-crop interface.

Majority of the farmers (58%) did not take any preventive or corrective measure to reduce the harmful effects of trees on the crops. However, about 20% of them practiced lopping and another 20% dug trenches near or around the base of the trees to avoid obstruction in ploughing by the roots. About 2% farmers tied up the leaves of young palm trees to facilitate ploughing and laddering and to reduce the size of the shady area due to the canopy.

Table 2. Age of trees up to which crops can be grown without significant yield reduction

Species	No. of observations	Age of trees	Standard deviation
Palmyra palm*	4	10.5	3.4
Mango	3	6.7	3.8
Mahogani	3	5.7	0.6
Jackfruit	10	5.3	2.2
Babla	25	5.2	2.8
Sissoo	3	4.7	2.1
Date palm*	43	4.6	1.3

*In case of palms crop yield is reduced up to the age mentioned in the table

Table 3. Farmers' perception of yield reduction of different field crops grown under trees

Species	No. of observations	Yield reduction (%)	Standard deviation
Mustard	33	29	21.4
Chickpea	20	29	24.1
Lentil	48	24	20.1
Rice	52	23	18.1
Jute	47	23	18.7
Aroids	13	18	16.5
Wheat	4	18	11.9
Turmeric	10	16	9.5
Potato	5	11	11.4

Interaction with other farm components

Typical farm households in Bangladesh have homestead, croplands- small or big, ponds or backyard ditches, livestock and poultry and trees. Farmers derive different kinds of products and services from these components to meet a variety of household needs. Because household activities are directed to meet these needs. Farmers try to optimize the uses of all these farm components. This results in various types of linkages among the components.

From our previous discussions on the multiple uses of trees, we can see that farmers get fruits from many trees and juice from the palms which are consumed as food. Wood and leaves of some trees provide fuel which is in very short supply

in some parts of the year and in some areas of the country. Abedin and Quddus (1990) reported that rainy months were the most critical period for fuel shortage; in some areas farmers suffered from fuel shortage during two-thirds of the year. Landless and marginal farmers suffered more than the medium and large farmers. They identified more than 13 types of fuel material used by the farmers among which branches of trees, leaves, wood and bamboo together contributed 42% of the total requirement. Use of trees and tree products as fuels saves cowdung from being burnt for cooking and thus increases the opportunity of its use as manure in the crop fields. Leaves and fruits of trees provide fodder for animals.

Leaves and branches of trees and bamboos are used for fencing in the homesteads and crop fields; some shrubs are particularly preferred for fencing plots of vegetables and spices. Agricultural implements are made from some trees; others provide timbers and construction material. Leguminous tree species fix atmospheric nitrogen and help improve soil fertility. Trees are also used in controlling soil erosion. Some plants have medicinal values; bamboo and cane are used for making handicrafts. In the homesteads trees give protection against storms and keep the dwelling areas cool during summer.

Agroforestry-Environment linkages

Control of soil erosion: Erosion is one of the important causes of serious deterioration of soil conditions. When soil is eroded, plant nutrients associated with this soil are removed to places where these are not required, for instance, in the water ways, lakes and reservoirs. When sediments eroded in a catchment reach the streams, the sediments themselves, nutrients contained in them and absorbed chemicals can act as pollutants and affect the environment. At the same time, when the top-soil is eroded, the productivity of soil can be reduced to a great extent. In agroforestry practices, trees/plants play vital role in controlling soil erosion mainly through interception, infiltration etc.

Interception: Trees act as a sponge to intercept much of the precipitation, part of which is absorbed and substantial part of which flows down the stems and drips from the foliage. The interceptions of precipitation by tree cover hold particular relevance to flood control and vary with the crop densities and tree species. It may be mentioned that 20% of rainfall is checked by tree cover, whereas ground shrubbery checks about 10%. In addition, the forest floor also intercepts rainfall to the extent of at least 5%. In this way, grossly 35% of rain drops are checked. Tree cover prevents rapid run-off of water and thereby checks soil erosion.

Infiltration: The decomposed tree cover in the form of humus improves physical and chemical properties of soil. It improves soil texture, builds its water-holding capacity and significantly neutralizes the impact of rainfall, surface run-off and erosion.

Most of Chittagong Hill Tracts of Bangladesh (CHT) is steep slopes. Shifting cultivation, locally known as jhum, dominated, both in terms of area occupied and percentage of farmers engaged. Several other land use systems, such as annual cash crops dominated by root crops, agroforestry, horticulture and tree farming have been gradually evolving in CHT. Annual cash crops and agroforestry are the keenest competitors among them. Analyses, therefore, were conducted on the three land use systems: jhum, annual cash crops, and agroforestry. Soil erosion is a barrier for sustainable agricultural land use in CHT. Some reports indicate that there is considerable variation in soil loss among the practiced agricultural land use system in CHT (Uddin et al., 1991-92; Gafur, et al., 2000; Shoaib, 2000 and Chowdhury, 2001). Soil erosion varies from one land use system to another (Table 4). It is therefore necessary to examine the magnitude of soil erosion under each land use system. While soil loss rates are considerably higher than the soil formation rates under annual cash crop and jhum systems, they are less than the formation rates under agro-forestry systems. Net soil loss under annual cash crops is more than 80 ton ha⁻¹yr⁻¹ and more than 26 ton ha⁻¹yr⁻¹ under the jhum system. However, under agroforestry there is net gain of 5 ton ha⁻¹yr⁻¹ (Table 1). About 60,000 families engaged in shifting cultivation covering an area of about 85,000 ha of the hill forests reserves. The extent of soil losses due to shifting cultivation in the hilly areas is shown in Table 5 (Farid et al., 1992). Due to high rates of soil erosion, profitability under cash crops decreases substantially as compared to agroforestry. As a result, differences in profitability between cash crop and agroforestry shrink.

The decrease in fallow period under jhum has led to the deterioration of faunal and microbial organisms, top soil loss, and land degradation due to slashing and burning during the period of heavy rainfall (Gafur, 2001). When topsoil is lost, the subsoil is exposed, which has a poorer structure and is more compact that reduces water infiltration capacity and increase surface runoff (Miller et al., 1985; Pimentel, et al., 1995; Alfsen et al., 1996). When soil and nutrients are removed, rooting depth for plants is reduced. Moreover, erosion increases the frequency and intensity of drought (Lal, 1987; Miller et al., 1985;). The most significant on-site effect of soil erosion is the loss of soil fertility (Alfsen and Franco 1996; Attaviroj 1990; Barbier 1998). This results from the depletion of organic matter and decreased availability of phosphorus, nitrogen, potassium, and other trace elements. Farid and Hossain (1988), based on data collected from 215 sample sites in CHT, found considerably less (25–40%) availability of organic carbon, nitrogen, phosphorus, and potassium in eroded soil than in noneroded soil. Similarly, Gafur (2001) and Borggaard and others (2003) reported nutrient loss due to soil erosion in the Bandarban district of CHT. Hill farmers therefore face a bleak future, with Jhumcultivation becoming increasingly unsustainable.

In response, the Bangladesh Agricultural Research Institute (BARI) launched the Hill Farming Research and Rehabilitation Programme (HFRRP) in the hilly areas during 1998-2005. The aim of this programme was to gradually replace Jhumcultivation by establishing Multi Strata Fruit Orchards (MSFO) on farmers' hills. This new technology has been found suitable for preventing soil erosion and degradation, and in increasing the cropping intensity of the area (Paul and Hossain, 2001). Jhum farmers, it has been found, can increase farm income by adopting this technology. Under the HFRRP, BARI has established a number of MSFOs, mostly on non-tribal farmers' hills, spreading over three hill districts of Bangladesh.

In Bangladesh, there is evidence that the use of contour hedgerows on steep hill slopes (40- 50%) can reduce erosion by 55-80% and runoff by 30-70% compared to shifting cultivation (Khisa, 2001). Several agro-forestry production techniques, designed with locally adapted trees and crops for different slope conditions, are found to optimise the production of agro-forestry crops and minimise environmental degradation in the hill region of Bangladesh (Paul and Hossain, 2001).

Table 4: Soil erosion in Chittagong Hill Tracts (CHT) under different agricultural land use system

Agricultural land use	Soil loss rate (ton ha ⁻¹ yr ⁻¹)	Natural rate of soil formation (ton ha ⁻¹ yr ⁻¹)	Net soil loss (ton ha ⁻¹ yr ⁻¹)
Jhum	41.23	15	-26.23
Annual cash crops	99.15	15	-84.15
Agroforestry	10.00	15	+5.00

Table 5: Land degradation (soil loss) due to shifting cultivation

Location	Predominant slope	Soil loss (ton ha ⁻¹ yr ⁻¹)
Khagrachari	60% area under 60% slope	10.10-67.00
Manikchari	46% area under 40% slope	12.00-120.00
Ramgarh	48% area under 40% slope	7.00-27.00
Rangamati	53% area under 40% slope	26.00-68.00
Raikhali	49% area under 40% slope	13.00-27.00
Bandarban	58% area under 60% slope	8.00-107.00
Teknaf	56% area under 20% slope	-

Maintain of soil fertility/organic matter level

Organic matter

Soil organic matter plays the key role in maintaining fertility of soil. Its main effects are to improve soil physical properties and to provide and reserve nutrients released by mineralization. During decomposition of herbaceous and woody residues, there is a loss of carbon and release of nutrients. The remaining materials become converted to soil organic matter or humus.

Nitrogen fixation

Leguminous trees/plants in agroforestry practices are a good source of nitrogen, play a significant role in soil improvement. Nitrogen fixing trees and shrubs growing within agroforestry system are capable of fixing about 50-100 kg N ha⁻¹ year⁻¹. The nitrogen returned in litter and prunings may be 100-300 kg N ha⁻¹ year⁻¹. (Nair 1984, and Dommergues 1987). Another major role of tree is to improve the efficiency of nutrient cycling. Mechanisms involve uptake from lower soil horizons, reduction of leaching loss by tree root system, balanced nutrient supply and improvement in the ratio between available and fixed minerals.

Root biomass

Root biomass of trees is typically 20-30% of total plant biomass (Young, 1989). Roots form an appreciable store of nutrient and since they almost invariably return to soil, constitutes a substantial element in nutrient recycling.

Biological reclamation of saline and alkali soils

Various authors reported biological amelioration for reclamation of saline and alkaline soils by planting tree species resistant to salinity and waterlogging (Sheikh 1974; Sandhu 1978; Yadav 1980; Annon 1982; Ahmed 1983).

Tree grown in salt-affected soil is reported to exert ameliorative effects by improving physical, chemical and biological properties of soil. Deposition of salts in the upper layer of soil is maintained due to greater loss of moisture through transpiration rather than through evaporation from the soil surface. Further, their shade reduces soil evaporation thus reducing the upward movement of ground water. In higher water table area, salts accumulated on the surface are prevented due to lowering down of water table as a result of accelerated moisture losses by trees. The trees through their deep and sturdy root systems open up the soil and improve water permeability, thereby facilitating leaching of salts (Yadav 1980). The incorporation of organic matter in the form of foliage etc. from the trees brings about favorable changes in the physico-chemical properties of soil.

Shelterbelt and Windbreak

Trees act as shelterbelt and windbreaks. The shelterbelt greatly reduces the wind velocity and leads to increased crop yield. In addition, trees act as screens and

check infiltration of wind-borne sand into the fertile soil and protect life and property to a great extent during cyclone, tidal surge etc.

Poverty alleviation

The total population of Bangladesh is about 160 million confined within 144000 km², making its population density the highest in the world. Over 50% of the population is below 15 years, and hence in the next 10 years, there will be an abrupt risk in demand for employment. 30% of the total GDP earned from agricultural sector appears to be limited, and other sectors are not creating sufficient new jobs. The population continues to grow at a rapid rate of 2.4% and poverty may now cause and certainly will cause in future an over-exploitation of natural resources resulting in environmental degradation. Moreover, the poor cannot afford to protect environment; their living conditions generate such wastes that are neither treated nor disposed off. The activities/cultural practices in agroforestry and material resources provide employment opportunities for the rural poor to a considerable extent, and thereby help in the alleviation of poverty.

Agroforestry-Farming Systems Linkage

Agroforestry is a holistic land use approach in which woody perennials are combined on the same land management unit with herbaceous crops and/or animals, either in the same form of spatial arrangement or temporal sequence. When woody perennials' interact positively with food crop farming and/or livestock production and improve the overall performance of the farm enterprise, it may be called an effective agroforestry. A systems approach to any activity starts with the concept that everything is connected and a change introduced in one component will induce a change in other parts of the system.

A farming system is a unique and reasonably stable arrangement of farming enterprises that a household manages according to well-defined practices in response to the physical, biological and socio-economic environments and in accordance with the household goals, preferences and resources. The farming system is a part of the larger systems and can be divided into subsystems e.g. cropping, livestock, fisheries, agroforestry and household or homesteads. Crops, livestock, fish, homestead vegetables, and forest outputs represent products of farming activities. Fundamental premise of farming system is that only farmers can perceive what is needed to improve their farming system. Technical feasibility, economic viability and social acceptability are part and parcel of farming systems. The goal of the farming systems research is to generate appropriate technology in the farmers' field.

National Farming Systems Research Program was initiated by NARS in 1985 with farming systems approach including livestock, fisheries and agroforestry in

addition to crops. Promotion of farming systems approach advanced through bottom-up research planning by developing proposals at field level with farmers and extension workers and institutionalizing the practices of regular review. This has strengthened research extension linkages but the linkage with the private sector institutions needs to be strengthened for rapid dissemination of innovations. The goals of the FSRD is total development of farmers to increase income for improved standard of living and social status with on-farm and off-farm interventions involving livestock, fisheries, crops agroforestry and homestead production components. This development should be sustainable and focused on resource-poor farmers.

Understanding the linkages between farming systems and agroforestry is extremely important for the success of a farming systems approach involving agroforestry as a component. Agroforesters hold baseline data and information about improved technologies crucial to the system analysis and designing process. Equally, data gathered through farming systems can be usefully employed to help determine agroforestry-priorities.

To bring appreciable changes in farm produce level the following are needed:

- Technologies that suit farmer production environment;
- A strong extension system to feed the farmers with recent technical information and strengthening the research with feedback from them;
- Appropriate policy support to keep farming profitable.

Intercropping

Intercropping is the growing of two or more crops simultaneously on the same field such that the period of overlap is long enough to include the vegetative stage. The crops are not necessarily sown at exactly the same time and their harvesting times may be quite different. Two types of intercropping are described below:

Mixed Intercropping (also called mixed cropping): Refers to any cropping arrangement, where there is irregular broadcasting or mixing of crops within the rows.

Row intercropping: Refers to an intercropping system where at least one crop is planted in rows.

In an intercropping system, component crops are used to refer to individual crops making up the intercropping, while sole crop refers to a component crop being grown alone, generally at optimum population and spacing. Intercropping yield rate refers to the yield of a component crop when grown in intercropping and expressed over the total intercropped area.

A farming system includes all the activities performed on a farm to fulfill the needs and objectives of the family. Farming system is participatory, holistic, interdisciplinary, and involves farmers and encourages linkages.

Livestock component: Cows, bullocks and water-buffalo are next to crops in importance. Livestock contribute 6.5% to the gross domestic product, whereas crops contribute 36.8%. Effect of alternative cropping systems technologies on agroforestry needs to be estimated. Following change in cropping systems influences type and number of species grown on particular lands:

- Quantity of feed and fodder both from home production and by purchase with price for each type and source of feed.
- Labor used for growing, watering and working on plant species.
- Straw treatment with urea in baskets, plastic bags and or stocks to test both value for storage and value as measured by performance of animals consuming the feed.
- Relay legume or maize crop to minimize tillage for food grain and for storage to be directly or after storage.
- Use cows for draft with seasonal breeding to avoid season of heavy work during late pregnancy and lactation.

Fishery component

Ponds and haors contribute 3% to the water resources for inland fish production. Grass carp eats leaf. This has created new area for agroforestry, especially where polyculture of fish is practiced. Agroforesters need to find out the right species and grow them in abundance to support fish culture.

Homestead Production Systems

The homestead of a farmer in Bangladesh is a multipurpose production and utilization center. Approximately 70% of wood and 90% of fuel wood and bamboo come from rural homesteads. Cattle, poultry, goats, a few plants of different cucurbits, other vegetables and trees for multiple uses are raised in different combinations on and around the homestead. These production activities are almost exclusively looked after by the women folk but have tremendous impact on family income and expenditure. These aspects should be carefully studied to see interaction with other components of FSR. Alternatives should be tested putting emphasis on family nutrition, small cash earning throughout the year, family fuel needs and employment of the women labor force at the family level.

Agroforestry component

Forestry occupies about 8% of the land area, and forest products make up about 5% of the total value of all agricultural products. Most forestry improvement projects in Bangladesh are concerned with production on forest reserves.

However approximately 70% of the timber and building material and 90% of the fuel wood and bamboo come from the rural homestead. Some tree species, such as mango and jackfruit are multipurpose, producing fruit and timber. The twigs and dried leaves of all trees are used as fuel for cooking. The young shoots and bark of the drumstick tree are often eaten as a vegetable, while the leaves of jackfruit trees are fed to goats and sheep. Fruit, timber and seedlings are also sources of cash income for the farm family. Just as with the livestock sub-system, the long life span of trees and their multiple uses complicate FSR model in agroforestry. Initial studies usually focus on the introduction of new fast growing species. More recently, attention has been given to improving the productivity of trees through fertilization of micronutrient and the use of plant growth hormones, particularly in the case of mango trees, to prevent flower dropping and fruit splitting. Attention has also been given to pest control and pruning management.

As the process of land fragmentation continues, the general trend is toward an increase in the number of homesteads each year. This means that nursery facilities and nursery management techniques are also potential areas of FSR intervention. Survey information suggests that there is a difference in species composition and forestry management on landless and landed farms with larger land holdings. Shade trees are detrimental to vegetable production on the homesteads with limited land areas. This suggests the need for class specificity in approaches to agroforestry.

Village Tree Cultivation

The following studies are proposed for promoting village-tree cultivation:

- i. Bench-mark survey on homestead production by homestead size and income groups.
- ii. Sociological research to determine farmer and local community perception of the usefulness of trees, their views on such critical matters regarding choice of species and their willingness to cooperate with Government in management and protection of forest.
- iii. Identification of high-yielding and fast-growing fuel wood species and other multipurpose crop for on farm-trials.
- iv. Identification of light-demanding and shade-tolerant agricultural, horticultural, forage and medicinal plants for intercropping with tree species in planting both on government forest land and on marginal and wasteland.
- v. Research on the development of multi-storied forest with multiple use species for timber fuel, fodder, food and medicine.
- vi. Development of techniques for maximizing sustainable production of tree fodder and fuel wood using such techniques as branch wood, lopping, pollarding, coppicing and hedgerow management.

vii. Studies on agricultural, horticultural and forest trees crop mixtures.

Agroforestry technologies (released for general use)

Inventory of technologies available with specific technologies

Bangladesh Agricultural University has developed three promising multistoried agroforestry system in three layered canopy configuration. Three multistoried agroforestry models based on coconut, mango and sissoo has demonstrated beneficial effects in terms of return per unit area. These agroforestry models have wide scope to adopt in 20 million homesteads, hilly areas of Chittagong and Sylhet and other waste lands in Bangladesh.

i) Coconut based multistoried agroforestry system

It is a three layered garden (Figure 1) consisted of coconut at the top layer, guava and lemon at the middle layer; and the vegetables, spices and the medicinal plants are at the ground layer. Coconut + guava based multistoried agroforestry system and coconut + lemon based multistoried agroforestry system allowed, respectively 42 to 46% and 53 to 58% sunlight for the growth of vegetables, spices and medicinal plants (Bari, 2009). The upper layer occupied by coconut was thirty years old and the spacing of plantation was 8m x 8m. As the middle or second layer plant, guava and lemon both were five years old and were in full bearing condition. Spacing between guava and / or lemon and between rows was 3m x 3m. This system is economically viable.

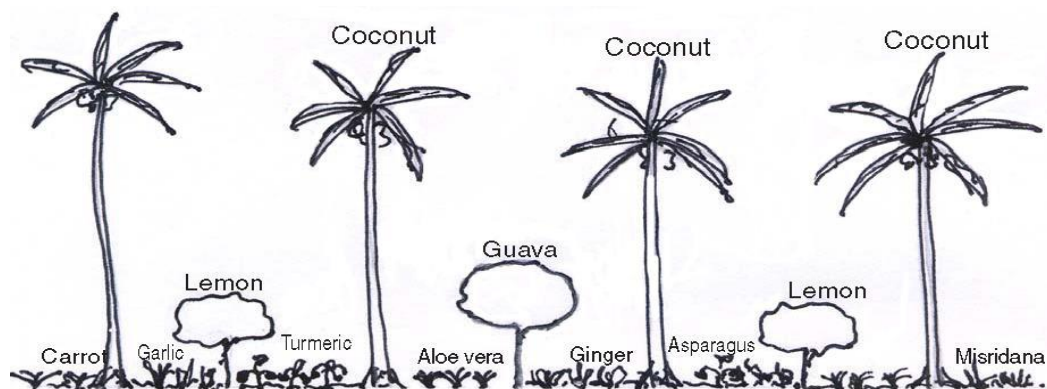


Figure 1. Schematic presentation of Coconut based multistoried agroforestry system

ii.) Mango based multistoried agroforestry system

It is also a three layered garden (Figure 2) consisted of mango at the top layer, guava at the middle layer; and the vegetable, spices and the medicinal plants were at the ground layer. Mango + guava based multistoried agroforestry system allowed 19 to 23% sunlight for the growth of vegetables, spices and medicinal

plants (Bari, 2009). The upper layer occupied by mango tree was thirty two years old and the spacing of plantation was 8m x 8m. As the middle or second layer plant, guava was five years old and was in full bearing condition. Spacing of guava plantation was 3m x 3m. These three storied system have also given positive economic return per unit area.

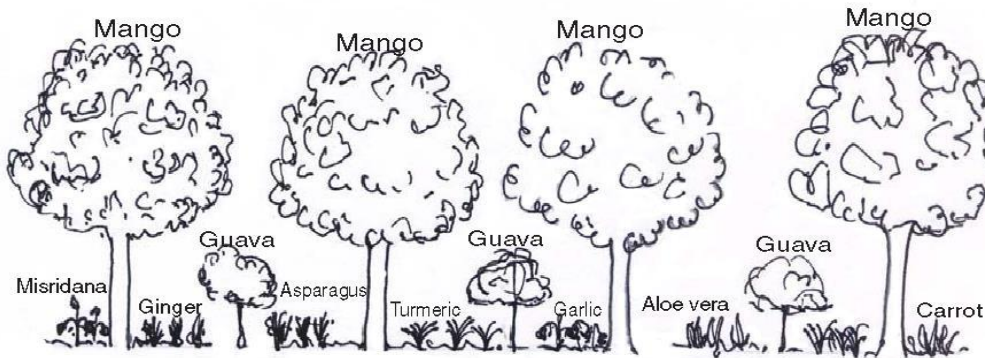


Figure 2. Schematic presentation of Mango based multistoried agroforestry system

iii) Sissoo based multistoried agroforestry system

It was also a three layered garden (Figure. 3) consisted of sissoo at the top layer; guava and lemon at the middle layer; and the vegetables, spices and the medicinal plants are at the ground layer. Sissoo+ guava based agroforestry system and sissoo +lemon based agroforestry system allowed, respectively 49 to 54% and 63 to 69% sunlight for the growth of vegetables, spices and medicinal plants (Bari, 2009). The upper layer occupied by sissoo, a good multipurpose and deciduous tree. The age of sissoo tree was eight years and the spacing of plantation was 6m x 6m. As the middle or second layer plant, guava and lemon both were five years old and were in full bearing condition. Spacing between guava and / or lemon and between rows was 3m x 3m. It was interesting to note that the economic analyses showed total net return of the multistoried agroforestry systems becomes higher than that of the monocropping of vegetables, spices and medicinal plants. So, integration of vegetables, spices and medicinal plants as ground layer crops in mango based multistoried agroforestry system is clearly preferred agroforestry system.

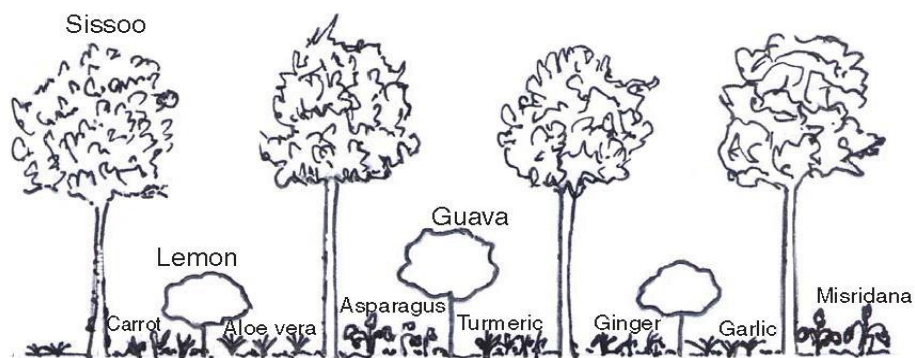


Figure 3. Schematic presentation of Sissoo based multistoried agroforestry system

iv. Multi Strata Fruit Orchard (MSFO) an innovative hill friendly agroforestry technology

In respect of soil erosion, nutrient loss and other disadvantages derived from traditional Jhum cultivation is losing its sustainability in the hilly areas. In response, the Bangladesh Agricultural Research Institute (BARI) launched the Hill Farming Research and Rehabilitation Programme (HFRRP) in the hilly areas during 1998-2005. BARI has generated new technology as Multi Strata Fruit Orchards (MSFO) in the hills. This innovative technology gradually replacing Jhumcultivation by establishing Multi Strata Fruit Orchards (MSFO) on farmers' hills. This new technology has been found suitable for preventing soil erosion and degradation, and in increasing the cropping intensity of the area (Paul and Hossain, 2001). It has been found Jhum farmers can increase farm income by adopting this technology. Under the HFRRP, BARI has established a number of MSFOs, mostly on non-tribal farmers' hills, spreading over three hill districts of Bangladesh.

v. BARI developed Homestead Agroforestry model for up scaling food security of resource poor rural farming. On-Farm Research Division of Bangladesh Agricultural Research Institute (BARI) has developed homestead based production system through its 9 FSRD sites with year round vegetables and fruit trees in different ecosystem representing plain land, rainfed, coastal, charland and hill areas of Bangladesh. An attempt has been made to view each farm separately and system performance of pre-intervention and intervention periods have been compared to assess the impact of homestead agroforestry interventions on farm productivity, income and employment generation and other relevant parameters. After reviewing all the homestead models it was generally observed that homestead based year round fruits and vegetables production was found promising and viable for raising production, economic return, nutrition supplementation and food security.

vi. BFRI developed agroforestry technology for the hill region

The Chittagong Hill Tracts is an agroforestry potential area. Since 1986-87, the Bangladesh Forest Research Institute (BFRI) is trying to develop appropriate agroforestry technologies. After accomplishment of significant on-farm research some potential agroforestry practices have been identified as suitable to the region. The alternate contour rows of tree plantation along with shade loving crops, bench terracing method, Sloping Agricultural Land Technology (SALT-1 and SALT-2), Differentiated Slope Agroforestry (DSA) method and Natural Vegetative Buffer Strip (NVS) are important.

Alternate contour rows of tree plantation along with shade loving crops

This agroforestry technology is easy and widely practiced by the farmers. Trees, preferably fruit trees or forest species (NFTs/MPT) are commonly grown in contour rows under close, 1-2 m plant to plant spacing. The double row approach of trees in contour is apparently suitable. In the double row approach the row to row spacing can be 1-3 m. Entire hillside can be brought into cultivation in this method. Within the tree rows 6-10 m interspaces are kept for cultivation of seasonal crops. In the initial stage, different seasonal crops like paddy, maize, chilli, sesame, papaya, pineapple etc. can be cultivated up to 3-5 years, but as the canopy coverage of trees will be increased, the shade loving crops like zinger, turmeric, aroid etc. have to be cultivated. In this technique soil erosion decreases in the order of 13.12 ton dry soil ha⁻¹ (Quader et al., 1991). The usefulness of this agroforestry practice is associated with effective soil conservation, production of seasonal/annual/biennial/perennial crops of mostly local origin as well as flexibility in field management.

Bench terracing method

The bench type terraces (not full terrace) of about 1.0 m wide and 3-5 m long are constructed along contour with 2-3 m interval throughout the selected hillside. The space between the bench terraces down the slope can be of 3-6 m. The bench terraces as well as interspaces, both along and against contour, are cultivated with seasonal, annual, biennial and perennial crops. In this method, the soil erosion is less, in the range of 16-22 t ha⁻¹ and water infiltration rate is high.

Sloping Agricultural Land Technology (SALT-1 and SALT-2)

It is an effective AF practices for humid and sub humid climatic conditions. Presently, several modifications of SALT have been evolved. Four of them namely: 1. Sloping Agricultural Land Technology (SALT-1), 2. Sloping Agro-forest Land Technology (SALT-2), 3. Sloping Agro-livestock Land Technology (SALT-3) and 4. Sloping Agro-fisheries Livelihood Technology (SALT-4) is effectively used in Bangladesh condition. This SALT approaches has gained wide popularity in Bangladesh. In this practice, various agro forestry crops and

livestock components suitable for the hill region can be accommodated. Several hedgerow species, e.g. gliricidia, ipil-ipil, desmodium spp., indigofera have been tried. Out of those, Indigofera tasmanilas hedgerow species showed better performance in SALT-1 and SALT-2. An estimation of soil erosion loss in SALT plot showed in the range of 15-20 ton ha⁻¹ and 12-18 t ha⁻¹ in the 1st and 2nd year respectively with 65% Slope gradient. The sustainability of SALT as an agro forestry practice is associated with slow but continuous improvement of soil fertility status by proper management of the systems organic matter, decreasing erosion and slowing the flow of rainfall down the slope.

Differentiated Slope Agroforestry (DSA) method

The major features involved with DSA are the division of the entire hillside into upper, middle and lower part. In DSA method, the less fertile upper soil is used for cultivation of forest species, the moderately fertile middle slope is left for horticultural crops, and the lower fertile most portion of the hillside is retained under cultivation of seasonal crops like maize, sesame, chilli, papaya and others. This is an easy practice that incorporates several early returning seasonal crops, which is commonly desired by the hill farmers. The cultivation area and production of seasonal crops in the hill region can be increased by the adoption of DSA practice. (Paul, 2001).

Natural Vegetative Buffer Strip (NVS)

Under NVS, the natural vegetation of local origin is intensively utilized for hedge purpose in place of nitrogen fixing hedge plants like in SALT. Trees and crops are commonly grown in the inter spaces of vegetative strips. The main advantage of this technique lies on the easy growing of vegetative strip with less labour cost and easy management. However it was shown that the NVS is less effective in terms of nitrogen addition in comparison to SALT (Garrity, 1999).

Extension of agroforestry technologies

Several proven agroforestry technologies of BFRI and other National Agricultural Research System (NARS) institute have been disseminated through on-farm demonstration activities. The combined actions of research and extension through FSRD approach is found effective for the hill region

Extent use of AF technologies

Extension of crop land agroforestry in northwest Bangladesh: Through participatory action research, the VFFP project of SDC developed a cropland agroforestry model, which is characterized by planting of at least three different species of trees along the field boundary at 8 cm spacing or throughout the field at 8m x 8m spacing in plots are more than 16 m wide, with regular branch and root pruning of trees. The VFFP project tested 40 different species of trees based on

farmers' choice in its action research plots. The results showed that Bokain (*Melia azedarach*), Eucalyptus (*Eucalyptus camaldulensis*) and sissoo (*Dalbergia sissoo*) was the most profitable tree species for cropland planting (Quddus, 2001) for 7, 10 and 13 years rotation, respectively. The farmers of the northwest Bangladesh adopted the cropland agroforestry in an extensive manner, which is readily visible. During 1997-1999 alone, the farmers in the VFFP command areas planted about 15.8 million trees in their crop fields.

Development of nurseries in private sector: Starting from 1991, VFFP trained thousands of poor men and women to be successful nursery entrepreneurs. The number of nursery men supported by VFFP stood at 6,000 (5% women) by 2007 (Quddus et al., 2007). For the business promotion and sustainability of the private nursery owners, VFFP and its follow-up projects (LEAF and AFIP) organized the nursery owners into Upazila based association with district level federations. Presently there are 305 Upazila nursery associations under 50 district federations and, in June 2010, a national federation of the nursery associations have been established (IC-AFIP 2010).

Establishment of QPM distribution and quality control system: Through the support of the AFIP project, the stakeholders have established a national distribution system of quality planting material (QPM) of fruit trees and timber trees. As part of this system, each of BAU-DH and BARI has established an Elite Fruit Tree Repository (at Mymensingh and Gazipur, respectively) and BARI has established four Elite Fruit Tree Multiplication Blocks at four Regional Stations of HRC-BARI; four organizations namely DAE, BADC, BRAC and Proshika have established 73 Foundation Mother Tree Orchards and multiplication nurseries; and 293 private nursery owners have established local Mother Tree Orchards. For timber tree seeds, BARI has established a distribution system involving the DNMSs and has trained selected nursery owners (DNMS members) in plus tree selection and seed handling techniques for local-level production of improved timber tree seeds. The DNMSs conduct 'annual quality audit' of the nurseries of their members in order to ensure quality of the planting materials produced by them. Through the initiative of the AFIP project, the Bangladesh Government has established (through gazette notification) a 'Nursery Guideline' to ensure quality control in the national QPM distribution system (AFIP 2010).

While farmers generally prefer to plant short rotation and high yielding tree species, many of the native tree species of Bangladesh are being lost due to lack of reproduction. Through financial and technical support, the Arannayk Foundation mobilized and capacitated 26 private nursery owners, distributed throughout the country, to produce and sell planting materials of endangered native tree species of Bangladesh, who now produce and sell 55-150 species of indigenous species, contributing to conservation of those endangered species.

Promotion of homestead agroforestry: The SDC supported VFFP, SHABJE and LEAF projects have trained thousands of poor farmers (majority women) in improved homestead agroforestry practices, including homestead space planning, vegetable cultivation, tree management, agroforestry and integrated pest management (IPM). Through financial support from VFFP, the Bangabandhu Sheikh MujiburRahman Agricultural University (BSMRAU) implemented an on-station research work, through which a number of summer, winter and year round vegetables and spices have been identified for different levels of shade in the homestead and other agroforestry environments. With the technical assistance of BFRI, VFFP conducted extensive extension work, including training of farmers and local service providers on improved management of bamboo groves. The latter intervention significantly increased production of bamboo in farmers homestead and the cash income from that.

Arannayk Foundation has been supporting a homestead agroforestry project implemented by three NGOs – two in Chittagong and one in Satkhira district since late 2006. Through this project, local NGOs have been supporting local farmers to restore and conserve the lost and endangered tree species of the respective areas in their homesteads along with complementary activities (income generating activities, improved cook-stove promotion, etc.) and to intensify and improve management of homestead agroforestry practices (mixed orchard, vegetable cultivation etc.) for increased income generation and family nutrition (Arannayk Foundation 2010).

Promotion of medicinal plant cultivation and marketing: SDC-IC took a special interest in medicinal plants and, through a systematic analysis of national demand and market potential, short-listed 20 species for promotion through a coordinated program involving the key stakeholders. Following this study, the LEAF project undertook extension program on medicinal plant cultivation in the homesteads of small and marginal farmers in the northwest region of Bangladesh. Focusing on the five most demanded and marketable species of medicinal plants namely Ashwagandga (*Withania somnifera*), Bashok (*Adhatodavasica*), satamuli (*Asparagas recemosus*), Bhuikumra (*Purera tuberosa*) and Tulshi (*Ocimum sanctum*), the project provided training on the production technology and mobilized planting material supply and marketing of the products. Initially 300 farmers were involved in this medicinal cultivation (in 2005), but the number has increased manifold by now. The LEAF-supported medicinal plant growers now supply Bashok leaves to the renowned pharmaceutical companies of the country like Square Pharmaceuticals and Acme Laboratories. Through Arannayk Foundation support, two NGOs, Juno Pawr and IDO, have been promoting conservation and cultivation of local medicinal plants in Rangamati Hill district of Chittagong and in KeshabpurUpazila of Jessore district in the northwest region of the country, respectively. In both locations, conservation gardens have been

established in several institutional lands and project participants have been cultivating a few commercially demanded medicinal plants in their homesteads for commercial purpose.

Extension of agroforestry in CHT: With Arannayk support, five NGOs are engaged in community capacity building for conservation of the community conserved forest and other natural resources in five pilot areas in the Chittagong Hill Tract, who are promoting agroforestry in the slopping lands to replace the traditional shifting cultivation through awareness campaign, training and demonstration. One of these NGOs, Anando, had developed a multi-tier orchard (MTO) model and a boundary line utilization (BLU) model involving pole forming timber trees, bush forming dwarf fruit trees like lemon, and pineapple in one of its earlier projects in Khagrachari, which are now promoted under the Arannayk supported projects. Another agroforestry model that is being promoted by another NGO in Bandarban is Pineapple + Mango against sole Pineapple, which is rapidly expanding in the hilly area due to its immediate profitability, but at the cost of high rate of soil erosion (Arannayk Foundation 2010).

Agroforestry Potential as CSA (Climate Smart Agriculture) technology

Bangladesh has great potentials for agroforestry development. Compared to the overall meager forest area of Bangladesh, the potential agroforestry land, by any measure, is substantial and amounts to almost 10.4 percent of the country's land surface. If the production potential of this land could be developed, it could dramatically change the production scenarios of both forestry and agricultural products.

Agroforestry Potential in Degraded Forest Land and Marginal Lands

i. Agroforestry is not a new land use concept, even though it received attention, publicity and prominence in recent years. Homestead and farm boundary plantings of fruit- and other utility trees, practiced for centuries in Bangladesh and other countries of the world, are evidences of agroforestry land management. However, agroforestry as a scientific and planned land use concept has emerged very recently. While developed countries pursued agroforestry on the principles of comparative economics in land management, the developing countries adopted this primarily as a means of problem-solving under pressing socio-economic adversities. Developing countries, particularly those with high population burden resort to agroforestry as the only viable option for reforestation of the fast degrading forest lands.

ii. Under tropical soil and climatic conditions, some form of agroforestry including silvi-pasture and silvo-fisheries is technically feasible, socially desirable and economically viable. In agroforestry land management practices, labor input is exceedingly high, 3-5 times higher than in the traditional block forestry because

of more intensive care and attention needed and given for agricultural crops. As illustrated in the previous section, the available potential land for agroforestry in the country is about 1.51 million hectares. If a 7-year rotation is prescribed for harvesting tree crops grown under the agroforestry production system, one-seventh of this area or 0.22 million ha could be brought under agroforestry plantation per year. Moreover, tree seedling nurseries, planting and maintenance operations, agricultural crop production practices, marketing etc, could generate about 90 million man-days of employment opportunities. Implementation of these programs will need a capital investment of about 2750 million taka in the rural sector; 80 percent of which would be labor wages. Agroforestry could thus add a new dimension to activity in the rural area. Along with agricultural practices, livestock rearing and fishery activities could help in solving the problem of rural unemployment and poverty.

iii. In resource building, the agroforestry production area of 0.22 million ha is capable of yielding 15.4 million cubic meter wood at harvest in a 7-year rotation period, even with a moderate production of 10 cubic meter wood per ha per year. Its value would be Tk. 3200 million even as fuelwood in standing sale. This means a gross 16 percent interest gained on the investment. Besides production of wood, agricultural crops, such as paddy, wheat, cotton, sesame, groundnut, pulses, vegetables and fish worth over Tk. 200 million would be produced annually in the first 3-4 years before shading effect of trees starts. This would greatly contribute to the food production of the country from the non- traditional agricultural sector and help bring prosperity to the rural poor in particular.

iv. The enormous potential for agroforestry indicated above is capable of changing the country's landscape altogether. The changes envisaged would not be confined to enhanced scenic beauty or abstract feelings. The block and strip plantations so created will constitute a multi-directional shelterbelts criss-crossing the length and breadth of the country. Such shelterbelts greatly reduce evapotranspiration and increase agricultural production by reducing the wind speed in dry seasons, and protect life and property of the citizens by diverting the devastating effects of Nor'westers, cyclonic storms and tidal surges.

v. The production and supply of wood in general and fuel wood in particular will greatly increase through implementation of agroforestry program in the country. As a consequence, use of agricultural residues and animal dung as domestic energy sources would prove unnecessary. The biomass so saved would be used, as organic manure for the farm land. This would help boost up farm productivity and production toward achieving self-sufficiency in food. Afforestation in the denuded hills and reforestation of the barren catchments of rivers, streams and lakes will augment dry season water outputs, facilitate cheaper irrigation and

increased crop production, and will reduce rainy season floods due to increased percolation of rain water in the forested floor.

Silvo-pasture potential

i. Organized dairy farming and ranches for raising beef cattle are almost non-existent in the country. Scarcity of fodder supply is the primary cause for this. A sustained supply of feed and fodder is essential for warranting systematic development of livestock industry. This is again a legacy of the generally low-output farming which prompted farmers to concentrate on cereal production on every available piece of land. Livestock rearing today is totally a marginal activity with the cattle solely dependent on agricultural wastes or cropland weeds. Literally, not a decimal of land in the country is devoted exclusively to fodder cultivation. For balanced growth and healthy sustenance of human beings, milk and meat products are indispensable. It is in the overall national interest that endeavors be made to foster milch and meat animal husbandry at the domestic and farming industry level.

ii. In the developed countries, major activity in agricultural sector is concerned with livestock rearing and fodder cultivation. In these countries, cereal output per unit area of land is high, and cultivation of only a fraction of the total farming land provides enough to meet the cereal requirements. The balance farm land is available for fodder production. Because of low-output farming technology in Bangladesh, poor input use and consequent low productivity, people can hardly think of putting their cropland under fodder cultivation. In such a situation, silvi-pasture on degraded forest land and marginal lands could be an alternative to help livestock development in the country. A combination of herbs, shrubs and fodder trees could be a sustainable source of feed for organized dairy farming and ranching. In Nepal, tree fodder is the principal source of animal feed. In Australia, New Zealand and whole of Africa, tree fodder is a major supplemental feed. Indonesia is well-adapted to cattle rearing under silvi-pasture and stall feeding conditions. Thus a great potential exists for the development of the livestock sector in Bangladesh through cultivation of fodder and forage in forests and marginal lands. Albizia, erythrina, ficus, artocarpus, figs, ipil-ipil, gliricidia, bamboo and a host of other species help the farmers to tide over adverse fodder situation during floods and droughts. Organized cultivation of these and other fodder species would greatly help development of livestock sector.

Experiments in New Zealand have firmly established that silvi-pasture on appropriate sites is more profitable than block forestry economically. In our situation also, the plain land degraded Sal forest and marginal strip lands could be managed more profitably and economically if put under silvi-pasture management with stall feeding arrangement for the livestock.

Silvo-fishery potential

- i. Shrimp culture is a foreign exchange earning sector for Bangladesh. Higher production of shrimp means more foreign exchange and greater economic good to the country. The Government and the people are equally eager to expand shrimp culture in the country. However, it must be realized that every place is not good a fish habitat. Every living being has a specific habitat of its own. This is why Chakaria-Sundarbans and Khulna Sundarbans are good sites for shrimp culture, and open surroundings of Potenga or Cox's Bazar beaches are not. These realities must be explored and evaluated before trying to expand shrimp culture all over the country.
- ii. The fresh as well as decaying leaves, twigs, flowers and fruits of mangroves offer essential fish meal. This is why fish is attracted to the mangrove surroundings. The forested environments also attract large variety of insects. These insects, their eggs and offsprings are attractive fish meal. The droppings of wild animals also supply essential fish food. Moreover, the shelter of the jungle is liked by fish as safe refuge to gather around. However, some 9000 ha of age-old mangrove forests of Chakaria-Sundarbans have been damaged for fish culture. Even the new plantation created under coastal afforestation scheme in the past 2-3 decades by spending millions of taka borrowed from World Bank were also damaged by clearing and diking for shrimp cultivation. These activities were undertaken through Government decisions because of lack of coordination and understanding.
- iii. There is no need to destroy forest for shrimp cultivation. Rather mangrove habitat is indispensable for long-term shrimp culture. Thailand, Indonesia, Indochina and Malaysia practice both intensive and extensive shrimp culture but nowhere by destroying mangrove forests. Such cultivation is done in the existing or by creating new mangroves under specified plan and designed ponds/canals alternating with forest blocks. And those are the ideal methods of estuarine shrimp cultivation. Irreparable damage has already been done to the mangrove and coastal afforestation efforts. Any further damage must be stopped.
- iv. Participatory silvo-fishery by associating the local community is the answer to sustainable fish cultivation program in the mangrove ecosystem. Education and training of the local community should constitute an essential component of the program to understand that mangrove and fish are intimately connected, that the mangrove ecosystem is indispensable for their economy and subsistence, and that their very existence against cyclone and tidal bores is dependent upon the presence of a tree-belt along the coast. Once the local community understands the importance of coastal mangrove forests for their economy and existence, their interest and participation would be ensured to resist any outside adventurism to disturb and destroy the natural habitat permanently.

v. Similar potentials for agroforestry, silvi-pasture and silvo-fishery exist in the inland river accretions (chars), 'Haors' and 'Baors'. A belt of trees along the fringes of 'Haors' and 'Baors' will protect the hinterland from wave action and scouring, and thus consolidate the banks. The trees will attract the indigenous and migratory birds for shelter and nesting. A symbiotic relationship of bird and fish will also foster fisheries and tourism development in the country. Trees could supply essential fodder and fuel wood to the surrounding community.

Here also, the strategy will have to be participatory. Without the willing participation of the neighboring people, resource building and its sustainability will not be feasible.

8. Constraints to up scaling agroforestry

Bangladesh has experience in agroforestry. The research organizations, forest departments, universities and the NGOs have been trying for greater adoption of agroforestry production systems in different ecosystems of Bangladesh through involvement of local people specially the poor target groups in agroforestry activities on marginal lands and forestlands. Different models of Agroforestry have been experimented and are now being followed by the extension organizations. The main constraints to us scaling agroforestry are:

- i. Land tenure issues
- ii. Lack of continuity, monitoring and proper supervision
- iii. Lack of proper silvicultural management
- iv. Credibility gap between the government and the beneficiaries
- v. Lack of marketing facilities
- vi. Lack of credit facilities
- vii. Lack of trained manpower
- viii. Lack of research backup
- ix. Lack of proper institutional arrangements
- x. Top down approach
- xi. Lack of recognition to roll of women and the other social group
- xii. Informations gap in agroforestry promotion

Potentials for improvement

Bangladesh is an agrarian country with overcrowded population. To bring substantial development in rural livelihood, development of agroforestry system through best utilization of land resources is deemed imperative. The potential arena for the adoption agroforestry technology and subsequent livelihood improvement are briefly stated here.

i. Adoption of multistoried agroforestry systems in Bangladesh

There is golden opportunity for multistoried agroforestry in Bangladesh. In Bangladesh there are about 20 million homesteads, where multistoried systems could be applied. Fruit specially mango and litchi orchard in northwest part of Bangladesh could be brought under this system which will provide continuous cash flow. Jackfruit orchard in the Madhupur, Gazipur areas of Bangladesh and in the forest plantation of Chittagong Hill Tracts, Sylhet where banana, pineapple, cassava, aroids could be grown.

ii. Adoption of planned integrated homestead agroforestry

Homestead forests are spread over whole villages in the country with an efficient private ownership. By providing a variety of goods and services, it acts as a buffer against the strong pressures on natural forests (Kumar & Nair 2004). It is reported that the homestead forests of Bangladesh provide about 70% of all wood consumed and 90% of all fuel wood and bamboo in the country (Alam et al. 1990). However, unplanned vegetation in the homestead vicinity does not result satisfactory return for the resource poor households. Therefore, the suitable combination of woody trees, fruit trees, shrubs, year round vegetables in different niches of homestead would result higher production, income generation, fuel energy supply, family nutrition and employment opportunity for the rural farmers. In addition, Apiculture, Sericulture and value addition of the homestead produce would improve greater sustainability of the livelihood improvement. On-Farm Research Division of BARI has generated around 9 homestead agroforestry based production model for different ecosystem. The dissemination of these model through extension agency, GO, NGO and other development organization would provide a remarkable improvement in rural economy in the country.

iii. Appropriate policy intervention for adoption of suitable agroforestry practices in degraded forestlands

Bangladesh, a densely populated subtropical country in South Asia, has huge degraded forestlands which can be reforested. The study shows that burning of biomass in the traditional cooking stove in Bangladesh has a severe implication on the deforestation and greenhouse gas emission to the atmosphere. The results show that tree tissue in the forests of Bangladesh stores 92 t C ha^{-1} , on average. The study confirms the huge atmospheric CO_2 offset by the forests if the degraded forestlands are reforested, indicating the potential of Bangladesh to participate in carbon trading for both its economic and environment benefits. So there is growing need for reforestation in view of ecological balance and economic stability. The traditional Sal forest extends over Madhupur Tract, as well as the districts of Dhaka, Mymensingh, Rangpur, Dinajpur, and Rajshahi. Most of the Sal forests have been denuded, degraded, and encroached upon by human intervention. The degraded forestland could be brought under suitable agro-

silviculture, silvi-pasture or other agroforestry system by adopting appropriate government policy which would enable more carbon trading and income generation.

iv. Improvement of marketing channel and institutional environment

The analysis of the marketing and institutional environment under which farmers work revealed that relatively low returns to agro-forestry largely result from inappropriate policies, complicated transit rules, an unfavorable institutional environment, and bureaucratic hindrances, which have distorted the prices of tree, fruits and other cash crops from the free market level. Transit policies, which requires permission from several authorities to harvest and transport timber incur considerable financial cost and time that frustrated smallholder tree growers and force them to sell timber in black market in tree traders at one third of market price. Some study show that profitability of agro-forestry increased several times if present constraints on marketing timber and cash crops are corrected. It also suggest that there is not only a trade-off but a win-win situation in agro-forestry, where soil erosion is minimum and income is considerably high if current market imperfection could be corrected and infrastructural and marketing facilities could be provided. It also shows that there is a great potential to increase smallholder income, as well as to slow down the present degradation process or even enhance the quality of natural resource base by removing constraints on agroforestry product marketing.

v. Incorporation of agroforestry in rainfed or dry farming croplands

All the rainfed or dry farming croplands can be considered for AF. These croplands are usually private lands in Bangladesh owned by the rural farmers. Carbon sequestration would take place in two ways: first, trees grown for timber and NTFP would sequester carbon and second, growing biomass on farm lands will lead to reduction in pressure on forest biomass. For the AF, silvicultural practices could be followed based on local indigenous knowledge and the farmer's choice.

vi. Strengthening social forestry system

Social forestry (SF) is an appealing land-use strategy by local poor landless community, has been in practice in Bangladesh. It has become a highly attractive and acceptable programme to the rural people, especially the landless and small farmers. It has generated sufficient resources and income to raise the rural poor above subsistence level and proved that community forestry can play a significant role in rural poverty alleviation in Bangladesh. The SF could be further strengthened through adoption of some issues such as ensure true participation of the target clientele, ensure tenurial security of both land and tree, integration of multifarious production system, integrate small and cottage industries, develop marketing infrastructure, develop marketing information system, create

community organizations, strong patronage from state and provide training and extension.

vii. Capacity buildup of the farmers

To get desired outcome from different agroforestry system, the selection of suitable species of trees and crops, their proper management practices, pest and disease management, quality maintain of the produce, market linkage is deemed necessary. Farmers' capacity on these issues could be raised through participatory training and other learning tools.

viii. Strip plantation in new roads and highways

The Forest Department (FD) takes the allotment of strips of land from the Authority of Roads and Highways, the Bangladesh Water Development Board and the Bangladesh Railway Board. The FD motivates local landless people and form groups (10-15 participants per group). The strip lands are allotted among the groups for plantation establishment and cultivation of agricultural crops (intercrops) on the strip land under the guidance of the FD. The strip plantation has been in practice in old roads and high ways. There is wide scope to bring new roads and highways under strip plantation which would promote greater adoption of agroforestry in the country.

Conclusions

Bangladesh is an agrarian country having dense population. To fulfill the growing need of this overcrowded population, it is urgently necessary to think about a joint production system utilizing land resources to achieve food and nutrition security, to fulfill the demand of fuel wood and timber, and finally conserve biodiversity. Greater adoption of planned agroforestry systems in all possible space of the country lead to combat the challenges of livelihood improvement. It is imperative to focus the technological advancement of agroforestry and formulate research and development strategies under climate change induced vulnerabilities. This paper reviews the scenario of vulnerability of agriculture to climate change, research and development progress of agroforestry, potentials for improvement, constraints etc. which may help to fix up strategies by the policy makers. It indicates that some strategies like strengthening comprehensive research and development program, an efficient coordination among all stakeholders, building the system from bottom up, organizational and institutional capacity building, strengthening marketing channel and institutional environment and appropriate policy intervention may give priority for sustainable development in technology generation and wide scale adoption of agroforestry in Bangladesh.

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Chapter 4

Technological Advancement in agroforestry systems: Strategy for climate smart agriculture technologies in Bhutan

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Abstract

Agroforestry in some form or other are practiced, in Bhutan, since time immemorial. Agroforestry is playing major roles in meeting the demands of the rural households for food, fuelwood for their energy requirement and fodder for their livestock. Agriculture is still the primary occupation for a vast majority of the people living in rural areas with main focus on growing cereal crops, livestock rearing and tree plantations along the field boundary and in homestead. In future, because of the small landholdings of the farmers, steep terrain of the land and low water retention capacity of the soil will necessitate the farmers to opt and go for intensive agroforestry practices. In almost all the agroforestry systems, trees are the fundamental component and with the increase in the buying power of the people, the demand for timber is increasing every day. The State Forest is not able to meet the demand of the resources. Agroforestry, therefore, will contribute in a big way to supplement the resources in meeting the demand which otherwise will come from State Forest.

Trees, shrubs and herbs, on agriculture field, or agroforestry practices, will safeguard the forest by producing small timber, fuelwood and fodder for the farmers, rebuild the fertility of land through soil conservation measures by arresting soil erosion and adding nutrients to the soil.

Agroforestry practices provide a sound ecological basis for increasing crops and livestock productivity thereby providing more economic returns to the farmers, assuring greater biodiversity and increasing social benefits on a sustainable basis. Agroforestry systems play important role in increasing the resilience of the crops and trees to climate change impacts. The combination of trees, crops and livestock can mitigate environment risks by reducing soil erosion, acting as water storage and provide assets and income from carbon, wood energy, improved soil fertility and enhancement of local climatic conditions.

With food shortages and increased threats of climate change, interest in agroforestry is gathering momentum for its potential to address various on-farm adaptations needs. As such agroforestry is seen as one of the most important options or alternate land use for practicing climate smart agriculture, across landscapes and agro-ecological zones, in Bhutan.

Introduction

Bhutan is a small mountainous landlocked country located in the Eastern Himalayas. It has a geographical area of 38,394 square km and a population of 0.721 million (NSB 2012a). The country is characterized by fragile mountainous ecosystem with elevations ranging from about 100 m in the foothills to over 7,500 m towards the north all within a range 170 km from the northern to the southern border. The most dominant land cover is forest, making up 80.90% of the land area including shrubs which account for 10.43%, cultivated agricultural land and meadows account for 2.93% and 4.10% respectively. Snow cover constitutes 7.44% while bare areas constitute 3.20%. Degraded areas, water bodies, built up areas, marshy areas and non-built up areas constitute less than 1% each. (RGOB, 2011)

The Renewable Natural Resources (RNR) sector comprises agriculture, livestock and forestry which are closely integrated at the farm level. This sector supports the livelihood of over 69% of the population which are mostly rural based and provides employment to over 56% of the total population. The current share of the GDP of the RNR Sector is 11.6% as compared to 22% in 2005. (RGOB, 2013).

Another vital role of the sector is the management and conservation of natural environment and maintaining the health of the ecosystem. A wide range of agriculture and horticulture crops is grown round the year in different agro-ecological zones from the wet-subtropical (150-600 masl) with a mean annual rainfall of 2,500-5,500 mm to temperate zones (2,500-3,500 masl) of mean annual rainfall of about 500-1,000 mm. (RGOB, 2011).

The major crops are rice, wheat, barley, maize, millet and buckwheat which are cultivated predominantly in the rain-fed dry land. The sector has diversified traditional cropping systems by growing cash crops such as apples, oranges and cardamom. Animal husbandry plays an integral part in the farming system and is the major livelihood of the highland farmers who dwell above 3,000 m where agriculture is limited to few short season crops. Forest is the primary source of fuelwood, timber, food and other ecosystem services. (RGOB, 2013).

Poverty in Bhutan

Poverty Analysis Report 2012, (NSB, 2012b) indicates that the poverty of Bhutan has been reduced to 12% in 2012 from 23.2% in 2007. This reduction indicates that Bhutan is well on its way to halving the proportion of the population below the poverty line by 2015. As per 2012 report the national poverty line is Nu. 1704.84 per person per month.

The poverty analysis report 2012 (NSB, 2012b) noted that despite the progress made in good governance and economic development in the country, poverty persists mostly in the rural areas (NSB, 2007). Poverty reduction strategies

developed over the years for improving the living standards of the poor have allocated the resources for developmental activities such as rural electrification, farm roads, basic health units, rural drinking water schemes, telecommunication facilities, and environmental conservation through the promotion of community and private forestry.

Agroforestry, concepts and definitions

Agroforestry is defined as an efficient, integrated and sustainable landuse system that combines agricultural crops, forest crops and/or livestock together on the same unit of farmland at the same time or in sequential manner. In an agroforestry there are both ecological and economical interactions between various components. It is an approach to alternative landuse based on deliberate integration of trees with crops and livestock production systems. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable landuse systems. Agroforestry includes various types of practices; including alley cropping, forest farming, shelterbelts, riparian buffer strips, and silvopastoral systems. It combines production of multiple outputs with protection of resources. It places emphasis on the use of multiple indigenous trees and shrubs. It is particularly suitable for low input conditions and fragile environment. It is structurally and functionally more complex than mono culture and the cycle of agroforestry system is always more than one year.

In dry environments, agroforestry systems potentially support livelihood improvement through simultaneous production of food, fodder and firewood without much affecting the climate change. Careful selection of species and good management of trees and crops are needed to optimize the production and positive effects within the system and to minimize negative competitive effects. It is an age old concept where trees, crops and animals have traditionally been raised together on small farms throughout the World. This concept was first practiced in the temperate zone due to the small family farms size.

Integration of activities takes place in the land used for agriculture, forestry and livestock in such a way to maximize production of foods and services for diverse requirements of rural communities. Modern agroforestry establishes a symbiosis relationship among agricultural crops, tree species and livestock rearing. In other words, these are complementary and beneficial to each other.

3. Agriculture and climate change

3.1 Agriculture

Agriculture is the primary source of livelihood for the majority of the population in Bhutan. Approximately 69% of the populations are involved in agriculture and in many occasions, majority of the labour force is contributed by women.

Agriculture in Bhutan is characterized by its labor-intensive activity with relatively low intensity of farm inputs. Most of the farmers in the country are small and marginal.

Among the agricultural lands in the country, an estimated 21% are wetland (irrigated), approximately 43% are dryland (rainfed), nearly 27% are used for shifting cultivation, approximately 3% are used for orchards and 1% is kitchen gardens. Major crops cultivated in Bhutan are maize and rice. Maize accounts for 49% of total domestic cereal cultivation, and rice accounts for 43%. Rice is the major staple crop (RGOB 2011).

Agriculture in the country includes cultivation of paddy and other minor cereal crops. It is the primary crop in those regions where proper irrigation is available. Apart from paddy, other crops like wheat, barley, oil seeds, potato and different vegetables are also cultivated in these lands. Maize is mainly cultivated in dryland regions at lower elevation. Forests act as the source of livestock fodder and organic materials for the purpose of development of fertility. Forests are also responsible for regulating the availability of water for agricultural purpose.

The primary goal of agriculture in Bhutan is to raise the per capita income of the people living in rural areas, to enhance self-sufficiency in staple crops, and to increase the productivity per unit of agricultural land and the farm labour.

Agriculture is hampered due to irrigation problem, rough terrain, poor soil quality and limited arable lands. But several other factors have contributed in the development of agriculture. These factors include improved quality of various cereal seeds, oil seeds, and vegetable seeds, use of fertilizers, mechanization process and trained agricultural experts.

3.2 Climate change

Climate is the average of weather usually spanning over more than several decades and it is a long term change in the statistical distribution of weather over period of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average e.g, greater or fewer extreme weather events. Climate change may be limited to a specific region, or may occur across the whole earth.

To a large extent change in the climate is effected by natural causes but nowadays with the advent of developmental activities taking place across the globe the anthropogenic factors have overtaken in causing the change in the climate. There are ample evidences that anthropogenic factors have been influencing the change in climate on a global and regional scale. So far the changes have been largely incidental due to the emissions of greenhouse gases which trap long wave radiation, thereby warming on a global level, and the emissions of sulphates which reflect solar radiation, thereby cooling on both a global and regional level.

A mix of methane and other gases strongly absorbs infrared radiation. Methane, if emitted in the atmosphere has big role in contributing to the change in climate. Another important contributor is chlorofluorocarbon.

3.2.1 Impacts of climate change

Climate change is one of the greatest social, economic and environmental challenges of our time. Apart from natural causes, anthropogenic factors are the major causes that are affecting the climate to change. This, in turn, is having impacts on rainfall, temperatures, forest fires frequency, health, heritage and biodiversity for current and future generations. Water resources are also seriously impacted around the globe because water is intimately tied to other resources and social issues such as food supply, health, industry, transportation and ecosystem integrity. Human health is affected directly and indirectly by climate change through extreme periods of heat, cold, storms, and climate-sensitive diseases such as malaria, skin related diseases like skin cancer.

The other impacts could be fast depletion of ozone layer due to excess emission of CFC, CO₂ and excess use of fossil fuel contributing to global warming and destroying our only protection against sun's harmful radiation. Climate change will not only bring more frequent extreme weather events and cause significant sea level rise and quick melting of glaciers in the mountains but is also very likely to threaten crop yield which could, in years to come, lead to even more hunger in the world. This is because climate change will likely make plants more sensitive to infectious diseases.

3.2.2 Mitigation Measures for climate change

Mitigation measures can be defined in the context of climate change, as a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Climate change mitigations are actions to decrease the intensity of radioactive force in order to reduce the potential effects of global warming. The following broad areas need special attention:

3.2.2.1 Reduction of Green House Gases

The most obvious solution to tackle climate change is to significantly reduce greenhouse gases emission, most notably CO₂, methane, nitrous oxide, and ozone. It is embarrassing that the world's richest countries want to take a free ride on this issue, by letting other nations lead the way in reducing their greenhouse emissions.

3.2.2.2 Carbon Capture and Storage

Carbon capture and storage (CCS), alternatively referred to as carbon capture and sequestration, is a means of mitigating the contribution of fossil fuel emissions to global warming. The process is based on capturing CO₂ from large point sources, such as fossil fuel power plants, and storing it in such a way that it does not enter

the atmosphere. It can also be used to describe the scrubbing of CO₂ from ambient air as a geo-engineering technique.

3.2.2.3 Carbon trading and taxation

Many governments have set a limit on the amount of CO₂ an industry can emit. This limit, or cap, or permit is then given or sold to the industry. The industry can then release CO₂ up to that limit. If it needs to release more, it has to buy permits from other industries that have cut back on their CO₂ releases. This buying and selling of permits is called carbon trading. The purpose is to reduce CO₂ emissions. Businesses that are able to cut back do so, and save money by selling their spare permits. Businesses that buy permits are paying extra for the right to pollute and it is in their own and their shareholders' interest to reduce their emissions as much as possible. Another method of mitigation of global warming considered by many Governments is through levy of carbon tax. This method would involve imposing an additional tax on the use of fossil fuels to generate energy.

3.2.2.4 Afforestation and Reforestation

Afforestation is the establishment of a forest or stand of trees in an area where the preceding vegetation or land use was not forest. Whereas reforestation is the re-establishment of forest cover either naturally or artificially, usually maintaining a same or similar forest type, and done promptly after the previous stand or forest is removed. Tree-planting can stabilize soils by increasing interception and reducing run-off, reduce flooding through the reduction of silting, improve soil fertility, provide timber and firewood, and counteract possible climate change through the absorption of the increasing levels of atmospheric carbon dioxide.

3.2.3 Adaptation Measures for Climate Change

Adaptation to climate change is a response to climate change that seeks to reduce the vulnerability of natural and human systems to climate change effects. Even if emissions are stabilized relatively soon, climate change and its effects will last many years, and adaptation will be necessary. Climate change adaptation is especially important in developing countries since those countries are predicted to bear the brunt of the effects of climate change. Adaptation alone cannot eliminate climate-related risks completely even with all the possible protective measures put in place. Climate change will impose additional economic, social, and ecological costs.

The capacity and potential for humans to adapt is unevenly distributed across different regions, populations, and the developing countries generally have less capacity to adapt. Adaptive capacity is closely linked to social and economic development. Some adaptation measures are appropriate in the short-term while others are more proper in the long-term. For example, changing crop varieties or

adjusting planting and harvesting months are short-term measures that can be used by farmers.

In short, it can be said that if everybody be more responsible in reducing the carbon foot print then to a large extent the global warming could be maintained at reasonable level. In addition to our individual efforts, far sighted government policy and commitments would be more important.

Solar radiation, temperature, and precipitation are the main drivers of crop growth; therefore agriculture has always been highly dependent on climate patterns and variations. Since the industrial revolution, humans have been changing the global climate by emitting high amounts of greenhouse gases into the atmosphere, resulting in higher global temperatures, affecting hydrological regimes and increasing climatic variability. Climate change is projected to have significant impacts on agricultural conditions, food supply, and food security. Overall, climate change could result in a variety of impacts on agriculture.

However, agriculture is itself responsible for an estimated one third of climate change. It is generally agreed that about 25% of carbon dioxide emissions, are produced by agricultural sources, mainly deforestation, the use of fossil fuel-based fertilizers, and the burning of biomass. Most of the methane in the atmosphere comes from domestic ruminants, forest fires, wetland rice cultivation and waste products, while conventional tillage and fertilizer use account for 70% of the nitrous oxides.

Over the past centuries, human ingenuity has led to technological advances in agriculture that have allowed substantial increase in crop yields stimulated to meet the requirement of increasing population. Intensive agricultural methods are reported to have detrimental effects on the environment. The agricultural sector has become one of the main driving forces in greenhouse gas emissions and landuse effects. For example, agriculture contributes to greenhouse gas increases through landuse in different ways:

- CO₂ emissions linked to deforestation in temperate regions: where forests and woodlands are cleared to make room for agriculture and pastures.
- Methane emissions from rice cultivation and enteric fermentation in cattle.
- Nitrous oxide emissions from fertilizer applications.

Together, these agricultural processes comprise 54% of methane emissions, roughly 80% of nitrous oxide emissions, and virtually all carbon dioxide emissions tied to land use. Deforestation for land cleaning purposes also affects regional carbon re-uptake, which can result in increased concentration of CO₂, the dominant greenhouse gas.

In Bhutan, some of the observed symptoms of climate change impacts on agriculture are loss of crops to unusual outbreaks of pests and diseases, erratic

rainfalls, windstorms, droughts, hailstorms and flash floods/landslides that are increasing annually. Most of the farmers are totally dependent on the monsoons for irrigation. The late arrival of the monsoons lead to drought while excessive monsoon rains cause natural disasters such as floods and landslides. Such extreme climatic events also put rural communities at increased risk as many remain disconnected in largely scattered settlements in the most challenging geographic conditions. In terms of food access and access to markets, as a mountainous and landlocked country, climate change not only affects the physical aspect of the farming environment such as land degradation but also affects food distribution systems and hence results in price distortion of essential commodities.

Due to late rain in the low lying areas of Bhutan, people who depend on seasonal rain for paddy cultivation have even stopped growing rice and thus quite a substantial area has remained fallow. This has resulted in the change in cropping pattern in some of the areas. Climate change not only affects the physical aspects of the farming environment in the form of crop losses but other aspects as well like land degradation, distribution systems and prices of the essential commodities. In the rugged mountain terrain where the settlements are scattered, the risks and impact will also increases. Therefore, while looking for adaptation measures, the solution lies not only to increase the crop yield and productivity of agricultural crops and improved efficiency of irrigation systems but also proper food distribution system and pricing.

4. Agroforestry systems in the country and their classification

Agroforestry is a land use management system in which trees or shrubs are grown around or among crops or pastureland. It combines agricultural, forestry technologies to create more diverse, productive, profitable, healthy, and sustainable landuse systems. However the system has to be socially and ecologically acceptable integration of trees with agricultural crops and/or livestock simultaneously so as to obtain increased production from plants and animals from a unit of farmland.

Implementation of agroforestry system as a formal full-fledged program has not been done in Bhutan at the moment but the systems are being practiced in some form or other since time immemorial. The systems in practice differ based on socio-economic condition of the local people, agro-ecological zones and the land where it is practiced.

Agroforestry systems practiced, in Bhutan, can be divided into the following two systems based on landscape niche or the land where the agroforestry is practiced i.e. (i) Farmland based agroforestry systems and (ii) forestland based agroforestry systems.

4.1 Farmland based agroforestry

Based on the systems, the farmland based systems can be broadly classified as follows:

4.1.1 Agri-silvicultural systems

The system involves growing agricultural crops and trees on the same piece of land simultaneously. Basically the system is a portrayal of conservation and production based on silvicultural practices complementing the agricultural activities. The system could be applied to wide range of agro-ecological zones and landscapes.

4.1.1.1 Taungya

The taungya system was first evolved in Burma in 1850's as a mode of planting large tract of teak areas. Later the system was adopted in many Asian countries as a means for raising forest plantations. In its original form the labourers were paid only in kind by allowing to use the forest land temporarily in return for their service in raising and protecting the plantations.

The system was in practice in early sixties and seventies in Bhutan. It was introduced in Bhutan by the Indian Forest Service officers who were working in Bhutan Forest Department under deputation in the southern part of the country. The system involves growing annual agricultural crops along with forestry tree crops during the early years of establishment of the forestry plantations. However, in Bhutan, this practice is abandoned due socio-economic related problems and a more organized social forestry system was introduced during the eighties.

4.1.2 Silvi-horticultural systems

This system involves simultaneously growing fruits tree/vegetable and forest trees on the same piece of land. Some commonly used silvi-horticulture systems include homestead agroforestry system. This is commonly practiced in all agro-ecological zones of Bhutan.

4.1.3 Agro-silvo-pastoral systems

4.1.3.1 Aquaforestry

It is the system of agroforestry where various species of fish are cultivated along with piggery and ducks. In this system trees and shrubs, preferred by fish, are planted on the boundary and along fish ponds. The main aim of this system is fish production and bund stabilization around the ponds. Locally available trees which can bear fruits and have beautiful flowers and provide shade are planted along the bund of the ponds. All species of trees are not useful to be planted around fish ponds because leaves of some tree species contain toxic substances which may be harmful for fish. Further large amount of organic matters falling inside the fish ponds are also harmful. Rotting plant materials raise the amount of CO₂ and

Methane in water therefore careful selection of trees to be planted around fish ponds is extremely important. Leaves of leguminous plants/trees like Moringa oleifera, and Leucaena leucocephala are good as fish feed on them when given as pallets. There are many ponds where warm water fish farming is practiced in southern part of Bhutan. Farmers get good cash income from the sale of fish in the market.

4.2 Forestland based agroforestry systems

The forestland based agroforestry systems can be divided into the following systems:

4.2.1 Silvopastoral systems

Silvopastoral system involves combination of trees and animals where grazing of domesticated animals takes place along with production of wood in a mutually beneficial way. Benefits of a properly managed silvopasture operation can enhance soil protection and increase long-term income due to the simultaneous production of trees/timber and grazing for animals. Silvopasture is believed to be the oldest agroforestry system used in the temperate regions of the world. Such systems have the potential to increase agricultural production in the long term. Silvopastoral system requires proficient management and the system can be sustainable even in harsh environments and fragile soils. This system combine with dairy and timber production with coniferous species offer promising opportunities for many farmers living in temperate regions of Bhutan.

4.2.1.1 Forest Grazing

Agroforestry can be aptly combined with silvicultural systems so as to bring about acceptable grazing. The system could be practiced in forest plantations which have becomes tall enough and gone beyond the reach of cattle or goats. Grazing in such plantations helps in the following manner:

1. The animals eat almost all the undergrowth thereby reducing the risk of fire hazards in plantations or agriculture areas.
2. Grazing in older plantations is one of the best examples of multiple landuse and shows that agroforestry is really a combination of trees, crops and livestock rearing in a same area.

In Bhutan free range grazing is practiced by the migratory cattle as well as resident cattle. Sometimes they are let loose in the younger plantations where massive destruction is done by eating away all the palatable plant species. It is, therefore, very important to allow grazing when the saplings reach beyond grazing limit by dividing the plantation areas in blocks and allow grazing alternatively.

4.2.1.2 Trees on rangelands

Rangelands are those areas of land, which by reason of physical limitations, have low and erratic precipitation, rough topography, poor drainage or extreme temperatures, which are unsuited for cultivation, and are a source of forage for free ranging native and domestic animals as well as a source of wood products, water and wildlife (Gyamtsho, Pema undated). In Bhutan, these areas are used for cattle and yak grazing, collection of firewood and non-edible products, medicinal or incense plants.

Trees are planted around such rangeland/pastures, especially in high altitude areas. Grasses are planted within the pasture. Government has initiated program for improving the rangeland/pastures for the people living in high altitude areas. In the lower elevation areas fodder trees are planted. Cattle are fed by lopping the branches of fodder trees.

The high altitude rangelands of Bhutan have sustained generations of yak herders, providing them forage for their herds and income from the collection of medicinal and incense plants. More recently, they have become important areas for recreation with the advent of tourism. Their importance in maintaining the integrity of Bhutan's river systems is getting increasing recognition. In order to ensure that the goods and services by these rangelands are sustained and further enhanced, urgent policy, legal and technical interventions are required (Gyamtsho, Pema undated).

4.2.2 Non Timber Forest Products collection

Bhutan is endowed with many non timber forest products that are used as food by the local people and also many fruits bearing plants and trees are available. People collect the fruits and sell in the local market. The most common are (a) *Persea fructifera* locally known as guli, (b) *Schleichera oleosa* fruits (c) *Paris polyphylla* (d) *Rubia cordifolia* (e) *Swertia chirayita* (f) *Illicium grithii* (f) Mushroom, Fern shoots and Amla (g) Bamboo (h) Daphne (i) *Ophiocordyceps* and many others.

4.2.1 Shifting cultivation

It is an agroforestry system in which plots of land are cultivated temporarily, then abandoned and allowed to revert to their natural vegetation while the cultivator moves on to another plot. The period of cultivation is usually terminated when the soil shows signs of exhaustion or, more commonly, when the field is overrun by weeds.

This practice has been termed as shifting cultivation because in this system the cultivators do not stick to a particular piece of land for cultivation. The cultivators select a patch forest/land and cut down all the trees, shrubs and herbs and leave everything to dry in the sun and then eventually set on fire. The clearing thus

obtained is taken up for cultivation. Seeds are sown by dibbling small holes in the ground by means of a wooden stick. Sometimes the seeds are also broadcasted. The length of time that a field is cultivated is usually shorter than the period over which the land is allowed to regenerate by lying fallow.

The practice is linked to ecological, socio-economics, and cultural factors including remoteness of the area. Due to increasing pressure of population the fallow period is gradually decreasing. In Bhutan the practice has been a way of life to certain communities living in far and remote corners of the country. However, recently the Royal Government is trying its best to attract the farmers, who are practicing shifting cultivation, for settled agriculture practices.

4.3 Agroforestry in traditional forest plantations

The system involves raising agricultural crops in forest plantations. Agricultural crops like maize, chilly, brinjal, cabbage, cauliflowers, mustard are planted in between two rows of forest tree species. The system was quite popular when taungya system was practiced during sixties and early seventies in Bhutan. Now since the taungya system is no more practiced in the country, raising of agricultural crops in traditional forest plantations is also discontinued.

4.4 Homestead Garden

Homestead agroforestry or home gardens are usually multi-storeyed mixture of large number of food, fuel, fodder and timber species growing as an intricate crop and producing a wide variety of products. Such crops are usually raised around individual houses and the trees are meticulously tended and are utilized for small timber and fuelwood. This system is known by both names as homestead agroforestry or home garden. In Bhutanese context it would be more appropriate to use the term 'homestead agroforestry' because the practice of the system is unique to Bhutan. Homestead agroforestry is one of the important forms of agri-silvicultural system of agroforestry. In this system tall trees are intercropped with medium shrubs and short annual crops to produce variety of foods and green manure besides reducing soil erosion. The system is basically a transition stage between tropical forestry ecosystem and arable cropping that mutually support the sustainable agriculture and forest ecosystems. The system has very high species diversity usually three to four vertical strata in a small area.

In Bhutan, farmers generally plant fodder and fruits bearing trees like *Artocarpus heterophyllus*, *Citrus spp*, *Psidium guajava*, *Mangifera indica*, intercrop with agricultural crops like ginger, turmeric, pumpkin, different varieties of beans, bhendi, onion, cabbage, sweet potato, banana etc. Chicken and ducks rearing is part and parcel of this system. Bananas are a common sight in many villages which are planted in cluster. The physical limitation such as remoteness of the areas forces the farmers to produce their basic needs by themselves and also throughout the year.

4.5 Benefits of agroforestry systems

1. Reduction of pressure on natural forests.
2. More efficient recycling of nutrients by deep rooted trees on the site.
3. Better protection of ecological systems.
4. Reduction of surface run-off, nutrient leaching and soil erosion through impeding effect of tree roots and stems on these processes.
5. Improvement of microclimate, such as lowering of soil surface temperature and reduction of evaporation of soil moisture through a combination of mulching and shading.
6. Increment in soil nutrients through addition and decomposition of litterfall.
7. Improvement of soil structure through the constant addition of organic matter from decomposed litter.

5. Association and interactions

5.1 Tree-Crop Association

The importance of the tree-crop associations has been known through long history of farming systems and the knowledge is handed over to later generations. Therefore the importance of traditional knowledge about tree-crops association cannot be overemphasized. Combination between trees and crops interacts dynamically and provides multi-faceted aspects of improvement such as increased productivity, enrichment of soil with organic matter and nitrogen transport of nutrients from lower layer to upper layer of soil. It will, also help in conservation of environment, improve microclimate of the area.

The knowledge of allelopathy is very important when tree-crop association is to be understood properly. Allelopathy is the deleterious effect of one plant upon another through the production of chemical inhibitors that are released into the environment. Allelopathic compound may be produced in any parts of the plants; however the highest concentration is in the leaves and fruits. These compounds are released in the environment through volatilization of leaching through leaves or exudation from the roots. An easily observable effect of allelopathy is the exclusion of shrubs and herbs from beneath trees such as walnut and Eucalyptus. In agroforestry allelopathic effect becomes problem when proper tree-crop association is not known. It is observed that most trees have negative allelopathic effects of crops therefore it is essential to explore what type of tree-crop interaction will have positive allelopathic effects on the associated crops.

Such combination may be introduced for beneficial results. As trees remain a part of agroforestry system for a longer period and most of them produce a large amount of leaves and litter their allelochemicals may play an important role in

overall improvement. If due emphasis is given allelopathic could play a major role in enhancing the production and productivity in agroforestry systems by having the better understanding of tree-crop combination.

Allelopathy is one area which has positive effects when it comes to combining both components for sustainable land use and to increase food production. Because these components co-exist, their allelopathic compatibility may be decisive to determine the selection of successful tree-crop association.

5.1.1 Purpose of growing trees by different categories of farmers

The inter-relation of the farming system, cattle, crops and trees is very significant and has to be managed holistically. A farmer cannot separate one from the other. Therefore the requirement trees are as much important to the farmers as their crops and livestock and also for protection of their farmlands from soil erosion.

The farmers grow different types of trees to obtain fodder for their animals, fruits for their family's consumption and also for sale besides small timber, poles, post, medicinal plants, food etc. Further the cost of fuelwood, in the market, is raising sharply therefore farmers plant trees for obtaining fuelwood required for their household consumption. Trees are also planted for ameliorating the climate, for shade and for enriching the soil through its leaves by adding carbon to the soil. In addition to food security, the small and marginal farmers are growing trees for livelihood security and additional returns also.

5.1.2 Tree-Crop Interaction

Tree and crops interactions may be influence or mutual or reciprocal action Component interaction refers to the influence of one component of a system on the performance of other component (Hasanuzzaman, undated). Agroforestry system is not a simply systems where farmers derive products from trees and crops or animals but a system where tree and crop and/or animal interact.

Interaction takes place both above and below the ground and includes a set of complex interaction relating to (a) radiation exchange (b) water balance (c) nutrient cycling (d) shelter and (e) other microclimatic modification (Hasanuzzaman, undated). Interactions may be usually complementary, supplementary and competitive. It is complementary when the interaction is positive or when there are complementarities between the components. It will be competitive when the interaction is negative.

When the interaction is based on components it is usually between tree and crops or tree and animals. The tree-crop interaction may be positive or producing or enhancing beneficial interactions. The negative interaction will decrease the production or enhance harmful interactions.

5.1.3 Perception of change in yield of different crops grown under trees

It is quite logical that trees do compete with agricultural crops for nutrients, soil moisture and light, but if the planting is arranged in such a way taking into consideration of the location, spacing, and direction that perhaps the trees will cause the minimum adverse effect on crops.

In Bhutan, except few scattered trees in farm bunds, farmers do not grow trees in the farmland. The practice of growing few fodder trees in the marginal land is acceptable to the farmers. It is believed that the crown of the trees hamper crop growing near or under the trees, produce light, water and nutrients competition between them. Birds and insects harbor in the trees and acting as host for diseases and pests. No formal study has been done, in Bhutan, on this issue but in general farmers believe that yield will be reduced if trees are planted intimately inside the agricultural field where crops are sown/planted.

5.2 Interaction with other farm components

Farmers derive various kinds of services and products from other farm system/components surrounding their houses and meet different kind of household needs. Thus there is strong linkage amongst different systems. For livestock system the trees provide shelter from rain and wind, shade from the sun, cover from predators and a diversity of foraging resources. This can be particularly valuable during cooler months and winter storms when protection of newborn are required from the vagaries of nature. It can also lead to significant savings in feed costs, survival and milk production.

Linkage with other component would be that farmers get fruits from the fruit trees he has planted around the households. Wood and branches of trees provide fuel when there is short supply during some season of the year. The branches of trees are also used for fencing the crop fields. Shrubs are also used for fencing vegetables gardens.

There are evidences that the overall biomass productivity of an agroforestry system is generally greater than that of an annual crop system although not necessarily greater than that of a forestry or grassland system. Agricultural tool handles are made from some trees planted by the farmers besides the provision of small timber for construction and fuelwood. Leguminous trees fix nitrogen and help improve the soil fertility. Trees are also used for controlling soil erosion and some species are used for medicinal purposes as well besides ameliorating the weather condition of the areas. Therefore there is a strong interaction with other farm components.

5.3 Agroforestry – Environment Linkages

Control of air pollution - Agroforestry has direct link with the environment in controlling the air pollution, ameliorating local climate, controlling soil erosion,

maintenance and promoting efficient nutrient cycling and in coastal areas reclamation or amelioration of salt affected soil.

Trees have the capability to manufacture their food through photosynthesis by using atmospheric carbon dioxide, water and solar energy and release oxygen thereby reducing the amount of carbon dioxide in atmosphere. This oxygen is used by human beings and animals as well for respiration and also between plants and animals. This process helps in maintaining the balance of oxygen and carbon dioxide in the air.

Reduction of greenhouse gas effect It is well known that trees absorb carbon dioxide and help keep the temperature within tolerable limit. If the atmospheric carbon dioxide increase slightly then it would cause a greenhouse effect which will result in excess heat accumulation on the earth surface. Trees have the ability to reduce this effect to a great extent.

5.3.1 Control of soil erosion

In agroforestry, the trees/plants play very important role in controlling the soil erosion mainly through interception and infiltration. Erosion is one of the reasons which cause serious soil deterioration. Plants nutrients present or associated with the soil are washed away to other places where such nutrients are not required. The eroded sediments and nutrients gets deposited in canals, lakes etc. and the deposited sediments themselves will act as pollutants and ultimately affect the environment.

The trees, if design and planted properly, will intercept the rainwater and part of which will be absorbed and quite large part will flow down the stems and drip from the foliage. The interception of precipitation by tree cover will help control soil erosion, and also in controlling the floods.

Bhutan being a mountainous country the importance of controlling soil erosion from the agricultural fields cannot be overstated. During the monsoon huge volume of rainwater gushes down the slopes and valleys eroding the top soil down the hills. In many instances the crops planted by the farmers are washed down. Land management practices by planting trees/plants including fodder trees in contour are given high priority by the Government. Still much needs to be done in this front.

5.3.2 Maintain or soil fertility/organic matter level

Leaves of tree/plant, after they fall on the ground, help maintain the soil fertility of the area. During the decomposition process of the herbaceous and wood debris there is loss of carbon and the nutrients are released and the physical properties of the soil are improved.

Leguminous plants, in agroforestry system, are good source of nitrogen which plays very important role in improving the soil condition. It is, therefore, very

important that nitrogen fixing plants and trees are also planted along with other trees so that the nitrogen is returned to the soil through pruning of leaves and branches. Root of plants store significant quantity of nutrients and also form good source of plant biomass and these materials when return to the soil constitute considerable elements in nutrients recycling.

5.3.3 Biological reclamation of saline and alkaline soils

Soil salinity is the salt content in the soil. Salts occur naturally within soils and water. Salination can be caused by natural processes such as mineral weathering or it can also come about through artificial processes such as irrigation. Plants obtain their requirement of water from the soil and when that water increases in salinity the plants will require more energy to draw the water through its roots and the plant can sometimes dehydrate even when there is water available, because it cannot keep up with the effort required to replenish its water supply.

Introduction of plants species that are salt tolerant into salt affected lands would not only provide green matter (biomass) for various uses but will also improve the land. It is possible to develop salt-tolerant plants, which can grow on the worst saline lands even when irrigated with brackish ground water. Such plants could be introduced on barren saline waste lands where no sweet irrigation water is available and ground water is also brackish. The green matter (biomass) produced on these lands could be utilized in numerous ways such as forage etc. Cultivation of crop also results in creating acidic condition in the soil and green manuring enhances it. It is therefore felt that cultivation of salt tolerant plants and their green manuring could create the desired acidic conditions to improve the soil structure and its permeability, which will help leach salt down. Plants growing in salt affected soil will have the following signs and symptoms.

- i. Slow, stunted growth compared to an identical plant in a low salinity area
- ii. Small stunted fruits.
- iii. Increased succulence of the leaves.
- iv. Leaves may be a darker green, or in some plants, take on a bluish green cast.
- v. Leaves then yellowing, mottling, browning and dropping off.

5.3.4 Shelterbelt and windbreak

Shelterbelt: Shelterbelt consist of trees and/or shrubs planted as a barrier to reduce wind speed and to protect crops, livestock, buildings, work areas and roads from wind and snow as well as enhance biodiversity. Shelterbelts are located around farmyards, adjacent to roadsides, waterways, on field boundaries or within fields and around livestock facilities.

It is important to choose plants that will grow well in the location. Therefore proper decision is required on designing the plantation modalities and the area available to plant the trees. The trees should be planted properly after preparing the sites and most importantly, control weeds after the trees has been planted.

Shelter belts are generally in blocks consisting of several rows of trees established at right angle to prevailing winds which generally deflect air currents; reduce the velocity of prevailing winds and protect the leeward areas from the desiccating effects of hot winds.

Windbreak: Windbreaks are linear plantings of trees and shrubs designed to enhance crop production, protect people and livestock, and benefit soil and water conservation. There are several types of windbreaks. Field windbreaks protect a variety of wind sensitive crops, control wind erosion, and increase bee pollination and pesticide effectiveness. Livestock windbreaks help reduce animal stress and mortality, reduce feed consumption, and help reduce visual impacts and odours.

Windbreaks are such structures which break the wind flow and reduce the wind speed. The effect of wind breaks enhance the crop and animal production by protecting livestock and crops from harsh conditions, check soil erosion along with wind erosion, protect livestock from hot and cold winds, and also provide them habitat. Generally tall and comparatively dense foliage trees and shrubs are preferred. They are commonly planted around the edges of fields on farms.

Properly planned windbreaks, around a house, can reduce the cost of heating and cooling and save energy. In cold countries windbreaks are also planted to help keep snow from drifting into roadways and even yards. Other benefits include providing habitat for wildlife and in some regions the trees are harvested for wood products. A further use for a windbreak is to screen a farm from a main road or motorway. This improves the farm landscape by reducing the visual incursion of the motorway, mitigating noise from the traffic and providing a safe barrier between farm animals and the road.

5.3.5 Poverty alleviation

School and College drop-outs are increasing alarmingly every year which is adding to the already saturated job market. These youths do not stay in the villages and already huge numbers are migrating to the urban centers. The urban centers are getting congested and the hygienic condition is worsening day by day.

Under such scenario if agroforestry is practiced then it has the potential to improve livelihood of farmers, including these young people, by providing multiple products from same piece of land at the same time. Some of the agroforestry options which would be beneficial to farmers are (a) rearing of improved breed of cattle for milk production (b) poultry farming in the backyard for eggs and meat (c) goat rearing for meat (d) vegetable production in the backyard and under shade of trees in home garden.

The agroforestry options mentioned above has great potential in alleviating the poverty status of the rural people. Government interventions by providing credit facility would be helpful to the farmers. The systems will definitely create positive impacts in conserving soil and moisture of the area thereby improving soil fertility and stabilizing sloppy lands. Since agroforestry is an integrated farming system it will provide multiple products such as food, fruits, fodder, forage, fuelwood and timber etc needed for farmer's day to day life.

5.4 Agroforestry –Farming systems linkages

As per FAO a farming system is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate. Therefore farming systems designate a set of agricultural activities organized while preserving land productivity, environmental quality and maintaining desirable level of biological diversity and ecological stability. The emphasis is more on a system rather than on gross output. The system may consist of several enterprises like cropping system, dairying, piggery, poultry, fishery, bee, keeping etc. these enterprises are interrelated. The end product and wastes of one enterprise are used as inputs in others. The waste of dairying like dung, urine, refuse etc. is used for preparation of farm yard manure (FYM), which is an input in cropping systems. The straw obtained from the crops is used as fodder for cattle's and for different field operations for growing crops. Thus different enterprises of farming systems are highly interrelated and linked with each other.

Since trees, crops, and livestock are the indispensable components of the farming system, agroforestry has very strong linkage with different components of the farming systems. People obtain cash income through the sale of forest, agricultural and livestock products. Agroforestry also help to enhance the biodiversity of the area through the conservation of habitats of birds and animals. The local farming systems heavily depend on forest and trees for their sustainability. Trees are the most important source of fodder for livestock, which in turn provides draught power for cultivation, food products such as milk and meat, and maintains soil productivity through compost and manure. Therefore understanding the linkages between the farming systems and the agroforestry is very important for the success of the farming systems approach involving agroforestry as a component.

5.4.1 Intercropping

Intercropping is growing of two or more crops simultaneously on the same field at the same time such that the period of overlap is long enough to include the vegetative stage. The objectives of intercropping is to produce more yield on a given land use of resources that would otherwise not be utilized by a single crop.

It is very important to take into account the requirement of soil, climate, crops variety etc. It is advisable to plant crops that compete with each other in terms of space, nutrients, water and sunlight.

The crops may be seeded at the same time (mixed intercropping) or they may be seeded at different times (relay intercropping). Strip intercropping is a production system where different crops are grown in wide strips (usually the width of a seeder) in the same field. Row intercropping is a system where at least one crop is planted in rows.

5.4.2 Homestead Production System

More than 69% of the Bhutanese population lives in rural areas practicing subsistence agriculture and almost all farmers have garden where several species of fodder species, fruits bearing plants and agricultural crops are grown and maintained by the households and the products derived from these plants are used for household consumption of the family. These are basically a multi-products production and utilization centers. The gardens are typically cultivated with a mixture of annual and perennial plants that can be harvested on a daily or seasonal basis. The farmers obtain small timber for their construction, fuelwood for their energy use and huge volume of bamboo comes from their bamboo groves maintained by them.

6. Agroforestry technologies released for general use

Agroforestry technologies suited to different land management systems are available and are in practice. The technologies aim to increase productivity while at the same time conserving the biodiversity, soil erosion control and improving the fertility and maintaining ecosystem resilience of the area. A standard agroforestry system encompasses synergistic interactions between woody and non-woody components to increase, sustain, and diversify total land output. They involve deliberate retention, introduction or admixture of trees, or other woody perennials, in crop/animal production to benefit from the resultant ecological and economic interactions. Agroforestry research is site specific that is why the technology developed in agroforestry differs in different agro-ecological zones.

Brief summary of important agroforestry technologies developed and released, in Bhutan, for general uses are given below:

6.1 Inventory of technologies released for general use

6.1.1 Agri-silvicultural based technology

(1) A participatory and multi-scale diagnosis for developing a soil conservation strategy for eastern part of Bhutan: Agroforestry technology to combat land degradation.

Land degradation due to heavy soil erosion and landslides had become a major constraint for sustainable land use in eastern part of Bhutan. Extreme diversity of

agro-ecological zones, the relative inaccessibility of the region made it difficult to develop a relevant land management strategy. To address this problem, a simple diagnostic multi-scale survey was developed in collaboration with land-users and extension agents. Preliminary picture of land degradation emerged for the region including major causes, geographical differentiation and trend in land degradation which helped to develop the guidelines for soil conservation strategy for eastern Bhutan. The extension service also increased their awareness program about land degradation which helped to make the future soil conservation program more effective.

(2) Climate smart approach: Water management – sustainable irrigation infrastructure.

- i. As part of the Climate Smart Agriculture Program, Water User Association Guidelines was prepared and based on that manual training for the farmers of Chuzanag Geog under Sarpang Dzongkhag were conducted. After the training farmers are able to manage their irrigation facility properly.
- ii. The Phangyul community in Wangduephodrang Dzongkhag have benefitted from the training and guidelines provided through the Climate Smart Agriculture Program. The training was aimed at water management for irrigation purposes.

(3) Upland paddy: A solution for production of rice under limited water

With the support of Agriculture Department and Climate Smart Agriculture Program the farmers at Chuzagang Geog under Sarpang Dzongkhag have taken up paddy cultivation of upland paddy in fallow drylands in Chuzagang. This technique has given the farmers an alternative to normal paddy cultivation where irrigation is a major problem. The farmers are now cultivating the upland paddy on a regular basis. The upland paddy program at Chuzagang is a success and all those farmers involved in the cultivation of upland rice are happy with what they could harvest.

(4) Technology for climate vulnerability assessment leading towards climate change adaptation.

The guideline for vulnerability assessment was prepared with the support of Climate Smart Agriculture support Program for the farmers of Sarpang, Tsirang and Thimphu. The adaptation plan were also developed and agreed with the farmers. PRA-related tools were used to discuss how changes in weather pattern impact their agricultural production.

(5) Non Timber based Technologies

Non Timber Forest Products (NTFP) play an important role in the daily lives and overall well-being of Bhutanese people especially among the rural farming communities. People earn substantial cash income through the sale of NTFPs which have medicinal properties. NTFPs often are a safety net for poor people during the off-farm season or whenever needed as a food security measures. Recognizing that the NTFPs significantly contribute to poverty reduction through the development of NTFPs resources the Royal Government approved a Strategic Framework for Collection and Management of NTFPs in 2009. Following this approval farmers group formation was started since 2010. Technical guidelines for resources assessment, management and marketing strategies were developed and released for the benefit of the people. Technical guidelines for the following most important NTFPs that has medicinal value has been released. Salient features of each species, where farmers groups have been formed are given below:

Paris polyphylla is a rhizomatous perennial plant which can reach upto one meter in height. It has spider like flowers with long, thread-like, yellowish green petals which are followed by small, scarlet berries. It is an important medicinal plant which is very popular in Chinese medicines. The rhizome has healing properties. In Bhutan commercial interest in Paris polyphylla started only few years ago. Farmers in Gomdar village have successfully transplanted root stock from the wild in their home garden. In 2011 the cost of one kilogram of dried rhizome was Nu. 1950. Farmers are getting good extra income through the sale of this NTFP.

Rubia cordifolia a woody climber used as medicine as well as for dye. The plant is abundantly found in central and eastern part of the country. The leaves are used to cure pain by rubbing on the skin and the stems are used to colour fabric and wooden floor. People collect the raw materials and sell to the traders in India since the market in Bhutan is very limited. Institute of Traditional Medicines uses *Rubia cordifolia* in their pharmaceutical unit. Local people get extra income by selling the raw materials.

Swertia chirayita: *Swertia chirayita* is a bi-annual plant and dies after seed dispersal in the second year. This species is found in the temperate Himalayas mainly ranging between 1,900 to 3,000 meters above sea level and spreads from Kashmir (India) to Nepal and Bhutan. In Bhutan the geog where it grows most abundantly is Lauri in Samdrupjomgkhar Dzongkhag.

It is one of the most important medicinal plants found in Bhutan. The plant is well known for its very bitter taste and its medicinal value. All parts of the plant

including leaves, flowers, roots and stems are used. People of Lauri Geog collect the plant and sell in the local market. It helps to remove intestinal worms and skin diseases and is used to ease constipation, urinary discharges, ulcers, stomach aches, asthma, bronchitis, and leucorrhoea. It is also used as a breath refresher and to reduce vomiting during pregnancy. Traditional Bhutanese medicine also uses Chirayita for blood purification and to cure common cold gout disease and even diabetes and malaria.

Illicium grifithii: *Illicium grifithii* is an evergreen medium sized tree that grows at an elevation from 1,800 to 2,800 masl. The tree can reach upto 30 meters in height. The flowering takes place from January to April, while fruiting begins from the end of April. Trees of atleast three to four years old with a diameter of three cm. can start to bear fruits. The star shaped fruits start maturing from September. In general *Illicium grifithii* bears fruits once a year in alternating cycles of one good productive year followed by a year of poor production.

The fruit of *Illicium grifithii* is used in oriental cooking for thousands of years now. It is used in baked foods and in making fruits jam. Most importantly it is used in Chinese medicine for centuries. It can act as stimulant, carminative, diuretic, anti-bacterial, anti-viral, and anti-cancer elements. Nowadays it is also used in pharmaceuticals for treatment of stomach ache, colic in babies and even facial paralysis.

In Bhutan, the local people use seed pods for various purposes such as flavouring tea, and to increase the strength of ara (local wine). It is also used for medicinal purposes like curing cough and toothache. The seeds of *Illicium grifithii* are poisonous and should be removed carefully from the pods. If the seeds are eaten accidentally then there is likelihood of food poisoning. The villagers collect the fruits and sell in the market. For domestic consumption they don't have to pay the royalty but if it is used commercially then nominal royalty is charged.

Mushroom, Fern shoots, and Amla products: Mostly women and children are involved in the collection of mushrooms, fern shoots and sale at the roadside and in the local markets. These NWFPs contribute to household food security and nutrition and also help to generate additional employment and income.

The community management groups engaging in Amla marketing is good for community groups as it means self employment; particularly during the off-agricultural season when there is no alternative income generating activity at hand at that point of time. The technical interventions are needed to reduce wastage as lot of wastage could be reduced during the de-seeding and shredding process. Although the income is not substantial, it is a welcome cash income for the farmers who live in remote areas and are mainly engaged in subsistence farming.

Bamboo and Daphne: Bamboo shoots are another product that is occasionally sold in the market but mostly used for home consumption. There is a national market demand for bamboo shoot pickle. There are some small Units that specialize in making pickles out of the young bamboo shoots. There is good opportunity for establishing link between these manufacturing Units and the local farmers.

In addition to that bamboos have very high demand in the countries which are used as flagpoles, scaffolding and house construction. Meeting the requirement from in-country production is not possible and large quantity is being imported from India every year. If the local farmers grow large scale plantations of bamboo then the farmers will have good opportunity to earn extra cash income from the sale of bamboo.

Daphne: Traditional paper making is one of the cottage industries with potential for enhancing rural economy especially for women self help groups by enhancing their skills in product design, innovation and going beyond primary processing.

People also collect various other species of NWFPs and sell to the local products buyers who use such products for manufacturing various other products. In the process people are able to make additional income by selling the products to local NWFP dealers. Lemon grass, Ruta and Pipla are some of the important NWFPs which the villagers collect and sell to the local products buyer Units.

Ophiocordyceps sinensis: The other high value NWFPs are *Ophiocordyceps sinensis* and lemon grass. Local people, who are resident of the area where *Ophiocordyceps* are growing, have exclusive right to collect *Ophiocordyceps* and sell to the traders in auction. The Department of Agricultural Marketing assists in conducting the auctions.

6.1.2 Silvo-pastoral based technology

- (a) The following technologies for silvopastoral development in Bhutan were developed by the Renewable Natural Resources- Research and Development (RNR-RDC) Cenetr in Jakar Bumthang. The technologies are well established and used by the farmers. The technologies have greatly helped the farmers in Bumthang. The most important and accepted technologies for silvo-pastoral development is given below.

Table 1: Agropastoral technologies released.

No	Technologies	Why it worked in Bhutan?
1.	White clover for improving permanent grasslands	1. Easy spreading, adapted to heavy grazing, high quality 2. Spreads through the grazing animal.
2.	Methods for establishing temperate fodder species	1. Developed in collaboration with farmers 2. Practical methods minimizing labour requirement and optimizing establishment success
3.	Seed production systems for temperate species	1. Development of appropriate production techniques through research 2. Seed purchased by the Government at attractive price
4.	Willow as a tree fodder for dairy systems with high milk production	1. Excellent qualities of willow 2. High dry matter production with no fertilizer inputs 3. Complements white clover to extend fodder availability into the dry season
5.	Silvopastoral systems with white clover	1. High returns from timber but only after 2-3 decades 2. Fodder provides opportunities for immediate benefits 3. Clover reduces weed problems and improves soil fertility
6.	Introduction of Napier	1. High yielding, wide range of adaptation, not dependent on seed supply

Source: RNR-RDC, Jakar, Bumthang.

(b) Propagation and management of *Ficus auriculata* as sub-tropical fodder species

Ficus auriculata is a species of fig tree which is widely used for augmenting winter fodder. It is the most important fodder tree within elevation of 200 to 2000 m a.s.l. The nutritive values of vary with elevations and the amount of annual rainfall and the nutritional quality in terms of fiber and CP content is superior at higher elevations. Tree fodders are an important fodder resource in the traditional farming system across the foothills of Bhutan.

6.1.3 Agro-Silvo-pastoral based technology

Warm water fish farming in the southern part of the country has helped the farmers to earn substantial cash income. The system involves rearing different species of fish along with ducks and piggery. Trees are planted along the ridges of the ponds. In many instances agricultural crops and vegetables are planted under the trees.

The technology developed by the Research Centers has become very useful farmers as they are earning good cash income from the sale of fish, meat and even small timber.

6.2 Extents and impacts of the technologies released

Different agroforestry technologies developed and released by the Research Centers have become boon to the farming communities in Bhutan. The technologies are well accepted by the farmers because they were developed in consultation with them. The impacts has been very promising and good because with the application of different agroforestry technologies the farmers' income level has increased manifold and their living standard also have gone up.

7. Agro forestry potential as CSA technology

Climate Smart Agriculture (CSA) includes actions at various scales within the full range of the farm plots, farming systems, landscapes, national and at global level. (FAO 2014) reiterates that Climate Smart Agriculture approach aims to tackles three main objectives. However the activities undertaken should be within the national food security policy and development goals of the national government. The objectives are:

- (i) sustainably improving food security by increasing agricultural productivity;
- (ii) building resilience and adapting to climate change;
- (iii) developing opportunities to reduce greenhouse gas emissions compared to the baseline if possible.

The CSA approach is designed to identify and operationalize sustainable agricultural development within the explicit parameters of climate change. CSA is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change.

Multiple challenges faced by agriculture and food systems need to be addressed simultaneously and holistically. In this context CSA is not a single specific agricultural technology or practice that can be universally applied. It is an approach that requires site-specific assessments to identify suitable agricultural production technologies and practices. The approach:

- j. is a location-specific and knowledge-intensive.
- k. identifies integrated options that create synergies and reduce trade-offs.
- l. identifies barriers to adoption and provides appropriate solutions.
- m. strives to achieve multiple objectives while prioritizing benefits and trade-offs.

- n. strengthens livelihoods by improving access to services, resources and markets.
- o. addresses adaptation and builds resilience.
- p. considers climate change mitigation as a potential co-benefit.
- q. integrates climate financing with traditional sources of agricultural investment.
- r. brings together practices, policies and institutions that are not necessarily new but are used in the context of climate change.

One of the common impacts of climate change to agriculture is water insufficiency at critical stages of crop development and excess rainfall when water is not required, which unfavourably affect crop production (loss of soil fertility due to soil erosion, outbreak of pests and diseases etc.). Water accessibility vis-a-vis other weather dynamics has serious consequences on agriculture production system.

The CSA program implemented by the Royal Government provides services to enhance agriculture productivity and income, through adaptation and building resilience to climate change and reducing greenhouse gas emissions from agriculture. The main objectives of CSA program is to create awareness for farming communities in climate change through capacity building and demonstrations; develop appropriate assessment and planning tools to assess threats of climate change on farming communities; identify and adapt suitable CSA options, mainstream CSA in research and development of the Department of Agriculture.

A better livelihood for the Bhutanese farmers is at the fore-front in planning CSA activities and the same is serviced by working closely with the Ministry of Agriculture and Forests at the national level, and with subsistence farmers, farmers groups, Water Users' Associations and cooperatives through the extension service networks of the Dzongkhags and Gewogs at field level.

The CSA approach in Bhutan is on pilot sites, where farmer groups undertake specific adaptations and mitigation measures aligned to socio-economic and agro-ecological situations. A more productive and resilient agriculture is built on the sound management of water, pests-diseases and soil fertility.

Therefore in order to draw comparison on the potentiality of agroforestry as CSA technology, it is important to recognize the emerging concept CSA. Agroforestry has the potential to increase the resilience of crops/trees to climate change impacts.

Trees ameliorate the effects of climate change by helping to stabilize erosion, improving water and soil quality and providing better yields of fruit, fodder and

medicinal plants in addition to their usual harvest of crops and livestock products. Agroforestry is one of the most widely adopted climate change adaptation strategies along with the use of improved crop varieties and intercropping.

7.1 Agro-silvicultural potentials

Agroforestry is not a new concept. In various forms and models it was being practiced, by the farmers, from time immemorial. Farmers had been planting trees mixed with agricultural crops, fruits trees in degraded and marginal agricultural lands. It has been proved that agroforestry is a good and effective land management technique especially where soil erosion is widespread. In many countries trees planting along with agricultural crops are practiced for economic return through sale of small timbers required for various purposes by the farmers both rural and urban areas. Farmers can generate cash income through the sale of fuelwood as well.

Agro-silviculture is practiced in various forms and lands. In earlier days taungya was one important system where forest land was used to raise trees along with agricultural crops. The importance of trees in agri-silviculture is very high and the most pertinent functions are: (i) control of soil erosion (b) production of timber (c) production of fuelwood (d) amelioration of climate and (e) improving the soil texture and nutrients. The role of trees in soil erosion control may be direct or indirect. Directly the trees will check the runoff and soil loss and indirectly the trees also serve to stabilize the structures and to make productive use of land which they occupy.

7.1.1 Rotational practice

Various modes of rotational systems are practiced. The most commonly followed rotational practice is improved tree fallow which is basically aimed to simulate the effects of shifting cultivation but with the tree fallow consisting of planted species, selected for their soil-enrichment capacity or useful products. Shifting cultivation is one of the oldest methods of rotational practices of cultivating agricultural crops with trees. In this system agricultural crops are raised followed by short or long fallow period. Soil erosion is more pronounced or visible if the fallow periods are shorter especially in hills. The rotational practices may produce similar results like shifting cultivation e.g. good erosion control during the fallow period but with the danger of substantial erosion, and associated loss of carbon and nutrients, during the period of cropping. The practice would become more acceptable in systems in which a mulch cover is maintained by some means during the cropping period. The system has great potential as CSA technology.

7.1.2 Spatial mixed practice

Tree gardens have many storied/layered and plantation crop combinations including the homestead gardens are found to be very effective as a tool for

climate smart agriculture because it provide dense crown cover and regularly renewed ground cover as well. A wide range of agroforestry systems fall under the practice of plantation crop combinations, having in common that an agricultural tree crop is grown in combination with other plants, which may be taller trees above it (as in systems of shade trees over cardamom plantation), another tree crop (bananas) or a herbaceous crop. Few such examples are found in Bhutan e.g. cardamom plantation under the shade of trees. Very recently coffee is planted in southern part of Bhutan.

7.1.3 Spatial zoned practices

Hedgerow intercropping: A method of planting in which rows of trees are interspersed with rows of crops, improving the soil and providing nutrients, particularly nitrogen, to the crops. Hedgerow intercropping (also called alley cropping) has multiple objectives, including fertility maintenance, and may be practiced on flat or sloping land.

Sometimes the tree component is made up of single or multiple rows of trees, but more often it consists of a dense hedgerow. Hedgerow intercropping on slopes consists of barrier hedges, whilst a set of barrier hedges resembles a hedgerow-intercropping system. The same woody species are commonly used, and their erosion control functions are identical.

Multiple-row of hedges would be necessary if heavy storms damaged single rows by washing away whole plants. They would also be desirable if found to be substantially more effective in checking runoff or filtering out sediment. Another option is to plant a row of grass immediately above the hedgerow.

In systems of hedgerow intercropping on slopes, the functions of the hedges in soil conservation are (i) to check soil loss through the cover effect by laying pruning on the ground surface in the cropped alleys (ii) to reduce runoff, increase infiltration and reduce soil loss through the barrier effect (iii) to maintain or improve soil fertility through the decay of prunings and root residues and (iv) to develop terraces progressively through accumulation of soil upslope of hedgerows and stabilization of the risers by stems and roots. As a result of its multiple benefits and advantages the technology of spatial zoned practice has proved very useful tool in CSA practices.

7.2 Silvipastoral potentials

Silvipastoral system is the management of forests both for the production of wood and rearing of domestic animals. The trees and shrubs used primarily to produce fodder for livestock. In this system forest tree species for fodder purpose like *Artocarpus* sp. *Bauhinia* sp. and *Leucaena* are planted around the pasture in the sub-tropical zone of the country whereas in the temperate zone grasses like white clover, napier and fodder tree like willow etc are planted. Silvipastoral systems

help in producing multiple products like fodder for cattle, fuelwood for energy, small timber, leaf mould for organic manure. Besides that it helps to improve sustain the livestock productivity, nutritive value of animal feed and finally improve the farm ecology by reducing surface run-off and soil erosion. The system has big potential for climate smart agriculture practices in Bhutan.

7.3 Silvofishery potentials

It is the system of growing trees along the bund of fish ponds. The main product in this system is the fish followed by other products like piggery (meat), ducks and ultimately small timber from the trees that are planted around the fish ponds. Shade giving trees and fruit trees are planted along the embankment of the fish pond. The system is popular in the southern part of Bhutan where the climate is suitable for fish farming. Tree species grown along the embankment of fish pond are Melia azaderach, Leucaena species etc and fruit tree species are banana, papaya and pine apples. The main advantages of this system are (a) earn extra income through the sale of fish, fruits, duck and pigs and (b) the trees grown along the embankment of the fish ponds help in ameliorating the local temperature as well. This system, if implemented carefully, has great potential as CSA technology.

7.4 Silvicultural potentials

7.4.1 Trees in agricultural fields

It is quite common to find trees being planted in the boundary of the agricultural fields and along the raised bund areas. People prefer to plant fodder trees in the terraces for fodder production and fuelwood purposes. Fodder/broom grass like *Thysanolaena maxima* are also planted in places where soil erosion is likely to occur.

7.4.2 Sacred wood lots

In some part of Bhutan it is an old traditional practice to conserve and protect an entire forest or a small wood lot in the name of the village deity. This is prevalent in most villages in southern Bhutan. All religious rites are performed in its complex and nobody is allowed to fell the trees. It is also seen that a perennial water source is managed either in the forest or near it for common use by the villagers for drinking purpose.

7.4.3 Community and Private forestry

In addition there are community and private forests which are protected at the community level. The community forests are managed by the communities and felling, extraction of timber is done according to the management plan approved by the Government. Community members are allowed to collect fuelwood and

leaf litter for their bonafide uses only. Such sacred woodlots, community and private forests also have great potential in ameliorating the local climate and help in climate smart agriculture practice at the local level.

7.5 Other potentials

7.5.1 Water management

Water is very important for any development activities and since Bhutan is pursuing hydropower development in a major way the importance of water has become even greater because the main raw material for hydropower development is water. Other important areas are provision of safe drinking water for people living in both rural and urban areas including water for irrigation purpose. It is in this context, conservation, development; utilization and management of this important resource have to be guided by national Policy and Acts. Effective watershed management is crucial for water resource conservation and sustainable utilization.

The Royal Government is experimenting on Payment for Environmental Services (PES) initiatives that support drinking water supply of the downstream communities. Other PES initiative is conservation of the black-necked crane in Phobjikha through ecotourism, and watershed rehabilitation in Pachu-Wangchu valley. The initiatives focus on establishing relationships between the service providers upstream and the service users downstream with reference to a particular ecological service of the forests, such as sustaining drinking water supply, conservation of biodiversity, and watershed protection for the benefit of rural communities and conservation of environment. Agroforestry can play very important role in reducing the soil erosion that are triggered by surface run-off in slope areas. Rain water harvesting systems are also useful technology in conserving water and utilizing later for irrigation and for drinking purpose by livestock.

7.5.2 Land reclamation

Land reclamation is an integrated approach to converting disturbed land to its original state (ecological restoration) or to an alternative state with a different end use. It may be reclaimed from sea, ponds, salinity, landslide, soil erosion or degraded lands. Reclamation involves two distinct practices (a) involves creating new land from sea or riverbeds and the (b) other involves restoring an area to a more natural state such as after pollution or salination which have become unusable.

Land reclamation can be achieved with a number of different methods. The simplest method involves simply filling the area with large amounts of heavy rock, soil and then filling with clay and dirt until the desired height is reached. Draining of submerged wetlands is often used to reclaim land for agricultural use.

Such degraded lands can be taken up under agroforestry program and brought under vegetative cover through plantations of soil binding trees species, creepers and with some level of water management works. After the soil is improved reasonably the fruit bearing plants, fodder species can be planted including soil binding species and leguminous plants.

7.5.3 6 Reducing emission from deforestation and forest degradation (REDD)

The Department of Forests and Park Services is aware of the emerging financial incentive in the form of REDD⁺ mechanism which may accrue to rural communities. The development of policy guidelines initiatives is underway, which aim to capitalize on carbon storage of Bhutan's forests and to plough back funds for conservation, sustainable management of forests, and enhancement of carbon stocks. Later when the program is fully implemented the local communities would also benefit from the program.

7. Constraints to up-scaling agroforestry

Agroforestry, as a formal program, has not been implemented in Bhutan. However it is practiced in various forms and combinations under the Ministry of Agriculture and Forests. Therefore, first and foremost, it is very important that agroforestry is taken up as one of the full-fledged programs under the Ministry of Agriculture and Forests. There are many constraints for up-scaling this program in Bhutan. Some of the important constraints are enumerated below:

- (1) The land holding of the farmers, in Bhutan, is very small and being a mountainous country the fertility of the soil is also very low. Water has become a limiting factor in almost many villages.
- (2) Technical capacity to produce short rotation seedlings of important fodder and fruit trees are lacking. Further it is aggravated by huge cost of seedling production which the farmers are not able to afford.
- (3) Being a very mountainous country, the transportation facility for the farm produce to the market is very limited. Farmers do not feel encouraged to produce more vegetables, fruits and food from the agroforestry system because of the transportation and marketing problem. However, in due course of time, this problem will be sorted out.
- (4) There is large scale rural-urban migration of the young and able bodied people leaving behind old people in the villages. This situation has resulted in farm labour shortage.
- (5) Credit facility to buy land, improved breed cattle, pigs and pullets, is difficult resulting in reducing the buying power of the people and up-scale the agroforestry practices in the villages.

- (6) Lack of co-ordination amongst the relevant Government Organizations like Department of Forests and Park Services, Department of Agriculture and Department of Livestock.

8. Potentials for improvement

It should be understood that agroforestry, like any other system or strategy, will not have all the solutions to climate change adaptation, mitigation and food security. However, agroforestry practices definitely have substantial potential to help small farmers to improve their food security status, wellbeing and the environmental sustainability of their farms and landscapes.

In Bhutan, agroforestry is implemented in some form or other by the concerned line Departments (i) Department of Forests and Park Services (ii) Department of Agriculture and (iii) Department of Livestock. However it is felt that an independent stand alone program needs to be developed if the agroforestry systems are to develop and support the farmers in their effort to uplift their socio-economic standard. Adequate attention needs to be given for agroforestry research by the Research Centers.

Agroforestry technologies developed till now should be disseminated to all farmers and there should be mechanisms to link farmers aspirations, requirements with the knowledge of researchers so that the technologies developed would be useful to the farmers.

Agroforestry can be foundation of climate smart agriculture and contribute in helping those who depend on agriculture for their livelihoods to better adapt to future climate change.

Appropriate national level institutions need to be established empowering with enabling policy and legal instruments which will coordinate among different sectors across national and local level. The market accessibility need to be improved so that farmers are able to bring their produce to the market and sell them to enhance their household income.

9. Conclusions

Agroforestry is an approach to guide actions to transform and re-orient agricultural systems to effectively and sustainably support food security (FAO, 2014). It is widely accepted that agroforestry systems can play an important role in increasing the resilience to climate change impacts generally for small-scale farmers. The climate change is already negatively affecting forestry and agriculture presenting a triple challenge around food security and nutrition, adaptation to climate change and contribution to climate change mitigation. The climate smart agriculture is an important new approach to address food and nutritional security, adaptation and mitigation interventions.

Rather than approaching the solutions of climate change from a perspective of climate smart agriculture technologies alone it is more advisable to look at climate smart agriculture systems including the resources, practices and policies for sustainable outcome. It is important to accelerate an enabling environment that will speed up the climate smart agriculture practices not only at the technologies but also on the policies level.

The value of climate smart agriculture should go back to the local circumstances like environmental, resilience and enable them to move toward prosperity. It is necessary to go beyond food security, adaptation and mitigation to satisfy what the farmers expect from climate smart agriculture practices.

In the coming years/decades, agroforestry can offer solutions to many of the issues and constraints outlined above because it has the ability to reduce greenhouse gas concentration in the atmosphere and sequester carbon in addition to producing food and fodder, crops including meat, milk and other products from livestock and fishery components. The contribution of trees, crops and livestock mitigate environmental risk, creates a permanent soil cover against erosion, minimizes damage from flooding and acts as water storage benefitting both crops and pasture.

Agroforestry systems offer an important opportunity for creating synergies between actions undertaken for mitigation and adaptation on climate change which provides opportunities to increase the resilience of agricultural systems. Agroforestry serves to enrich farmers through the harvesting of diverse products at different time of the year. Therefore agroforestry systems has great potential as a tool for climate smart agriculture in Bhutan where more than 69% of its population lives in rural areas and depend on agriculture, livestock and forestry for their livelihood.

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Chapter 5

Technological advancement in agroforestry system: Strategy for climate smart agriculture technology in India

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Abstract

Agroforestry has been in practice in one form or other in different parts of the country since long. Traditional agroforestry comprised of retaining trees on field bunds and/or inside fields or leaving a chunk of holding under natural vegetation. After advent of fast growing tree species, industrial agroforestry came into being with plantation of Poplar, Eucalyptus, Subabul, Acacia hybrids and Casuarina, etc. These species allowed cropping unabated and simultaneously yielded rich dividends to the farmers in terms of hard cash. Organized agroforestry research in India began in the eighth decade of last century when the Indian Council of Agricultural Research (ICAR), New Delhi launched the All India Coordinated Research Project (AICRP) on Agroforestry and later on established National Research Centre for Agroforestry (now upgraded as Central Agroforestry Research Institute) to accelerate basic, strategic and applied research in agroforestry. In addition to ICAR, Indian Council of Forestry Research and Education (ICFRE) and its regional centres, private institutions, NGOs and cooperatives such as WIMCO, ITC, BAIF, IFFDC, West Coast Paper Mills Ltd., Hindustan Paper Mills Ltd., National Tree Growers Cooperatives are also engaged in research and promotion of agroforestry in the country. Agroforestry and forestry research and education has been started in more than twenty State Agricultural Universities (SAUs).

Agriculture remains the primary occupation for a majority in rural India, and with increasing focus on rainfed areas, diversification of agricultural practices and the new initiatives in agroforestry are likely to increase in future. Agroforestry is playing a major role in meeting the demands of the rural households for fuelwood and fodder requirement of livestock. It is estimated that the total annual consumption of fuel wood is estimated at 216.42 m tonnes, out of which only 58.75 m tonnes is extracted from forests and rest is met through Agroforestry. The focus on small and medium industrial enterprises consuming a large proportion of

forest products is likely to boost agroforestry. The increasing urbanization and the growth of the Indian economy at the rate of 9% per annum puts pressure on environmental resources for physical infrastructure and consequently for wood based construction material and this would give a boost to agroforestry. Agroforestry research in the country has been accepted and emphasized by the researchers, policymakers and farmers for its apparent ability to contribute significantly to economic growth, poverty alleviation and environmental amelioration.

Introduction

Climate-smart agriculture (CSA) is defined as an agriculture that sustainably increases productivity, resilience, reduces/removes greenhouse gases while enhancing the achievement of national food security and development goals. The World Bank along with Food and Agriculture Organization (FAO), International Funds for Agricultural Development (IFAD), World Food Programme (WFP), United Nations Environmental programme (UNEP) and the Consultative Group for International Agricultural research (CGIAR) promote climate-smart agriculture, pointing to the potential of a “triple win” where farmers and pastoralists who are under the greatest threat from climate change could also play a major role in addressing it. This would increase yields (poverty reduction and food security), make yields more resilient in the face of weather extremes and slow onset climatic changes (adaptation), and make the farm a solution to climate change rather than being part of the problem (mitigation). IPCC (2007) reports that 13.5% of global greenhouse emissions can be attributed to agriculture and another 17.4% are related to forest conversion. FAO states that a transformed agriculture can contribute to climate change mitigation. However, climate change poses many threats to agricultural production, and a more productive and resilient agriculture will require better management of natural resources, such as land, water, soil and genetic resources including through those practices with effective mitigation potential as identified in the IPCC 4th Assessment Report (2007) such as restoring organic soils, cropland management, grazing land management and rehabilitation of degraded soils. The integration of agroforestry can play a major role in improving the capacity of both intensive and extensive systems to increase mitigation and adaptation effectiveness, while achieving food security and income generation goals.

Climate smart agriculture is being widely debated at present and there is a growing global recognition a transformation of agriculture is needed. However, the absolute need to feed a population of over 9 billion by 2050 remains, and it is important that the aspirations of climate-smart agriculture to increase yields and

food availability are not subjugated to climate priorities. An immediate implication is that there may well be a tension between the expansion of cropland to meet growing food demands which will increase greenhouse gas emission and the maintenance of other land uses such as forests that maintain ecosystem services including sequestration and emissions avoidance. Another and equally important approach should be through the introduction and expansion of tree based agricultural systems. Agroforestry has the capacity to meet many of the aspirations of climate smart agriculture. Trees on farms and in landscapes help to improve food security. Fruits and leaves contribute to human nutrition and fodder from trees feeds livestock. Appropriate trees, if well managed in crop fields can also improve the fertility and organic matter content of the soils and increase crop yields. Timber and fuelwood are harvests that can be used or sold, fuelwood still being the most important source of cooking fuel in many rural communities. Trees on farms and in extensive grazing lands also contribute to a broad range of ecosystem services that landscapes provide, such as improving biodiversity, soil health and water conservation. Trees also contribute to mitigation, as they sequester carbon in above and below ground biomass.

India had taken a lead in agroforestry research since organized research in agroforestry started world-wide about 25 years ago. The organized research was initiated in early 1970s through industry participation in plantation of commercial tree species through Indian Council of Agricultural Research (ICAR) institutes. As a follow-up, the All India Coordinated Research Project (AICRP) on Agroforestry was established in 1983 by the ICAR for conducting research work in collaboration with State Agricultural Universities situated in different agro-climatic zones. Since then voluminous data has been generated about both traditional as well as improved agroforestry systems and practices. Now, about 25 million ha area in the country (8.2 % of the total reported geographical area), is reported under agroforestry in both irrigated and rainfed agriculture which also includes trees outside forests and scattered trees on and off the agricultural fields. Considering the country's unique land-use, demographic, political, and sociocultural characteristics as well as its strong record in agricultural and forestry research, India's experience in agroforestry research is important to agroforestry development, especially in developing nations. Agroforestry has received much attention in India from researchers, policymakers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality, so that today agroforestry is an important part of the 'evergreen revolution' movement in the country. Twenty-five years of investments in research have clearly demonstrated the potential of agroforestry in many parts of the country, and some practices have been widely adopted. But the vast potential remains largely underexploited, and many technologies have not

been widely adopted. This situation is a result of the interplay of several complex factors. The understanding of the biophysical issues related to productivity, water-resource sharing, soil fertility, and plant interactions in mixed communities is incomplete and insufficient, mainly because research has mostly been observational in nature rather than process oriented. Methods to value and assess the social, cultural and economic benefits of various tangible and nontangible benefits of agroforestry are not available, and the socioeconomic processes involved in the success and failure of agroforestry have not been investigated. On the other hand, the success stories of wasteland reclamation, and poplar-based agroforestry show that the technologies are widely adopted when their scientific principles are understood and socioeconomic benefits are convincing. An examination of the impact of agroforestry technology generation and adoption in different parts of the country highlights the major role of smallholders as agroforestry producers of the future. It is crucial that progressive legal and institutional policies are created to eschew the historical dichotomy between agriculture and forestry and encourage integrated land-use systems. Government policies hold the key to agroforestry adoption.

India has announced the landmark National Agroforestry Policy 2014 that will mainstream the growing of trees on farms to meet a wide range of developmental and environmental goals. For planning and implementation, the Policy has recommended developing a sound database and information system on agroforestry. However, at present unlike forest cover and area under crops, exact estimates for area under agroforestry are not available. The accurate assessment of area under agroforestry can be done with the help of geospatial technologies as manual (traditional) methods of mapping take a relatively long time and high cost.

Agriculture and climate change

Climate change and its variability are emerging as the major challenges influencing the performance of Indian agriculture. Long-term changes in shifting weather patterns result in changing climate, which threaten agricultural productivity through high and low temperature regimes, increased rainfall variability, and rising sea levels that potentially deteriorate coastal freshwater reserves and increase risk of flooding.

Impact of higher temperatures under climate change tends to reduce yields of many crops; and encourage proliferation of weeds and pests. Although yield increases in some crops and other positive benefits have been noted in some regions of the world, the overall impact of climate change on agriculture is likely to be negative. Climate change will have a negative effect on yields of irrigated crops across regions, both due to increase in temperature and changes in availability of water. Rainfed agriculture will be primarily impacted due to

rainfall variability and reduction in number of rainy days (Venkateswarlu and Shanker, 2012). Each year one or the other part in the country is affected by droughts, floods, cyclones, hailstorm, frost and other climatic events. The fourth IPCC report clearly brought out the global and regional impacts of projected climate change on agriculture, water resources, natural eco-systems and food security. Among the several highly populated regions of the world, South Asia is categorized as one of the most vulnerable. Although climate change impacts are being witnessed all over the world, countries like India are more vulnerable in view of the huge population dependent on agriculture, excessive pressure on natural resources and poor coping mechanisms. Significant decline in production is likely to be caused by shortening of growing period, which will have negative impact on reproduction and grain filling particularly due to terminal heat stress and decreased water availability. Biodiversity will be also adversely affected, which in turn, will affect agricultural production. Poor people, especially those living in marginal areas of low agricultural productivity, depend on the genetic diversity. Climate resilient agriculture (CRA), encompassing adaptation and mitigation strategies and the effective use of biodiversity at all levels - genes, species and ecosystems - is thus an essential pre-requisite for sustainable development in the face of changing climate.

The Indian agricultural production system faces the daunting task of having to feed 17.5 percent of the global population with only 2.4 per cent of land and 4 per cent of the water resources at its disposal. With the continuously degrading natural resource base compounded further by global warming and associated climate changes resulting in increased frequency and intensity of extreme weather events, “business as usual” approach will not be able to ensure food and nutrition security to the vast population as well as environmental security (the need of the hour). The challenge is formidable because more has to be produced with reduced carbon and water footprints. To achieve this task of paving the way for climate smart agriculture we need to take several measures that will have enabling policies, institutions and infrastructure in place and the farming community be better informed and empowered with necessary resources. The major benefits CSA is as follows:

1. CSA helps to increase soil health and improve water conservation and availability on farms, with practices such as composting and other soil management techniques, harvesting and retention systems.
2. CSA promotes ways to reduce greenhouse gas emissions, such as: reducing encroachment of farms or ranches into forested areas, encouraging agroforestry systems with added planted trees and promoting more efficient use of fertilizer to help avoid methane emissions

3. Diversifying crops through CSA can help address food security and create alternative income opportunities and sustainable economic livelihoods for farmers.
4. It can also help reduce their vulnerability to crop losses in the face of climate change weather impacts.

Impact of climate change on India agriculture

Climate change impacts agriculture both directly and indirectly. The type and magnitude of impact will vary depending on the degree of change in climate, geographical region and type of production system. Assessment of impact of climate change is carried out through controlled experimentation and simulation modelling. Experimental results obtained are extrapolated on regional basis in relation to the projected climate change under different scenarios. The key influences are:

- Change in productivity, with reference to quantity and quality of crops.
- Change in agricultural practices like water use and application of fertilizers, insecticides, and herbicides etc.
- Environmental influences, particularly in relation to the frequency and intensity of soil drainage which may lead to loss of nitrogen through leaching, soil erosion and reduction of crop diversity.

Effects on agricultural crops

The major effect on crop is due to shortening of crop duration which is related to the thermal environment. Increase in temperature will hasten crop maturity. In annual crops, the shortening of crop duration may vary from 2-3 weeks, thus, adversely impacting productivity. Another direct effect in crops such as rice, wheat, sunflower etc., is on reproduction, pollination and fertilization processes, which are highly sensitive to temperature. The indirect influences operate through changes in water availability due to inadequate or excess rainfall and effect of increase in temperatures on pest and disease incidence.

Monsoon in India has become increasingly inconsistent and erratic in recent times. The number of intense rainfall events together with reduced number of rainy days has been noted during the latter half of last 50 years. Thus, risks of drought and floods have increased to the country's wet-season (kharif) rice crop. Statistical analyses of state-level data confirm that drought and extreme rainfall adversely affected rice yield in predominantly rainfed areas during 1966–2002. The drought has been found to have much greater impact than extreme rainfall events (Auffhammer et al., 2012).

In case of wheat crop the study indicated that every rise of 1°C in mean temperature, India could loose 4-5 million tonnes of wheat (Aggarwal, 2008). Under the current predicted changing pattern of climate by 2050, Indo-Gangetic Plains (IGPs) account for 15% of global wheat production. Here, as much as 51% of its area has to be reclassified as a heat-stressed, irrigated, short-season production mega-environment



(Ortiz et al., 2008). This shift would also result a significant reduction in wheat yields, unless appropriate cultivars and crop management practices are innovated and adopted by farmers. Besides all measurement, if weather does not support the crop cultivation that may affect the crop adversely. For example, during rabi 2014-15 rain during Feb, March and April 2015 coupled with high wind velocity adversely affected wheat, barley, mustard, chickpea and lentil. Lodging in wheat, barley and mustarly occurs in most of the field. Since, wheat and barley crops are at milking stage/dough stage and if lodging occurs at this stage then the yield may reduce up to 15 - 30%. Overall, the lodging in red soil is comparatively less as compare to black soil. Rain again occurs in first week of April 2015 coupled with high wind velocity, the severity of crop losses due to lodging and frequent rains at harvest stage in wheat, barley, chickpea, lentil and linseed crops have reached up to 55 - 70%.

Winter (Rabi) maize grain yield in India is projected to reduce with increase in temperature in Mid Indo-Gangetic Plains (MIGP), and Southern Plateau (SP). Spatio-temporal variations in projected changes in temperature and rainfall are likely to lead to differential impacts in different regions (Byjesh et al., 2010). In particular, monsoon season yield can reduce mostly in SP (up to 35%) and winter yield will reduce in MIGP (up to 55%), while upper IGP yields will be relatively unaffected. Developing new cultivars with growth pattern in changed climate scenarios similar to that of current varieties in present conditions could be an advantageous adaptation strategy for minimizing the vulnerability of maize production in India (Byjesh et al., 2010). Using field experiments and simulation models Singh et al. (2010) reported that growth and yield of maize was greatly affected by temperature changes associated with sowing dates. Yield was reduced in late-sown crops due to the harmful effect of chilling temperature. Irrigated wet-maize is projected to reduce yields by up to 18% in 2020 and 2050 scenarios. This adverse effect of climate change is projected to be about 23% in 2080 scenarios. Adaptation strategies such as improved and tolerant cultivar(s) managed under

improved inputs with additional nitrogen fertilizer can enhance the irrigated maize net production by about 21% in 2020, 10% in 2050 and 4% in 2080 scenarios (Soora et al., 2012).

Climate change may increase production of potatoes in Punjab, Haryana and western and central Uttar Pradesh by 3% to 7% in A1B 2030 scenario, but in the rest of India, particularly West Bengal and Southern Plateau region, the production may decline by 4-16%. It is primarily attributed to the rise in mean minimum temperature during tuber development stages which affects potato yield. The increase in temperature due to climate change may decrease harvest index (HI) of this crop grown in large parts of Maharashtra, parts of Karnataka and Andhra Pradesh. Even though, in the traditional potato growing belt in the IGP, the HI may remain more or less stable but pockets of high HI are likely to diminish (Soora et al., 2012; Singh et al., 2013a). Adaptation to climate change can increase the yields by 13-19% in different scenarios, thereby increasing the overall production by about 20%. Potato and vegetables mature early, and heavy crop losses will be noted when crops are exposed to abnormal increases in temperature (heat wave). The prolonged droughts during summer generally affected the crops like cocoa, black pepper, coconut, coffee, tea and cardamom along the west coast adversely in 1982–83 and 2003–04. Increase in night temperature in several parts of the country during winter 2010 adversely affected mango flowering (Rao et al., 2013). Grapes and its value-added products have also been affected by variable climate. The grape yields are expected to be reduced with the likelihood of change in the incidence and pattern of attack of insect-pests like mealy bug, thrips and mites. Similarly, the disease incidence pattern is also likely to be affected with a change in climate. This is evidenced by decrease in productivity during recent years from > 25 t/ha to 8 t/ha during 2009–10 and 12 t/ha in 2010–11 due to unseasonal rains which led to a serious infection of downy mildew (Sharma et al., 2013). Cashew nut, an important export-oriented horticultural crop is also likely to be affected by changing climate thereby affecting the export revenues. Climate change would pose problem for cashew cultivation since cashew is grown in ecologically sensitive regions such as coastal belts, hilly areas, and areas with high rainfall and humidity. The flowering, fruiting, insect-pest incidence, yield and quality of cashew nut and kernels are more vulnerable to climate variability. Unseasonal rains and heavy dew during flowering and fruiting periods are the major factors which adversely affect the yield and quality of cashew nut. Cloudy conditions, high relative humidity and heavy dew are favourable for outbreak of insect-pests and diseases. Drought conditions also drastically reduce cashew production (Rupa et al., 2013). Oil palm is grown as an irrigated crop in India. It is likely to be more vulnerable to climate change due to excessive dependence on ground water with poor adaptation mechanisms. The water requirement is estimated to increase by 10% for every

1°C rise in temperature. Under such situations, when oil palm yield decreases, small and marginal palm growers would be affected the most (Suresh et al., 2013).

Positive effect of climate change on agriculture

The crops grown under enriched CO₂ environment showed increased growth and yield as enhanced CO₂ affects the growth and physiology of crops, enhancing photosynthesis and Water Use Efficiency (WUE). Differences in physiology of C3 and C4 plants make C4 plants more photosynthetically efficient than C3, especially when the level of CO₂ is high. If the direct effect of CO₂ is included, yields are projected to increase for rainfed crops under both the A2 and B2 emissions scenarios in the 2080s. The increase is likely to be highest for rainfed maize under the A2 scenario, possibly because the higher CO₂ concentration would boost the yield of rainfed maize under the current water-limited conditions prevalent in some regions of the country. Global climate change may increase production of potato in Punjab, Haryana and western and central Uttar Pradesh by 3.46 to 7.11% in A1b 2030 scenario. The simulation results indicate that on an average, future climate would have a positive impact on productivity of rainfed soybean in the country. Increase in soybean yield in the range of 8-13% under different future climate scenarios (2030 and 2080) is projected. In case of groundnut, except in the climate scenario of A1b 2080, which showed a decline of 5% in yield, rest of the scenarios showed 4-7% increase in rainfed yields as compared to the baseline.

Agroforestry system and their classification

Agroforestry is a land-use system that involves socially and ecologically acceptable integration of trees with agricultural crop and /or animals simultaneously or sequentially, so as to get increase total productivity of plant and animal in a sustainable manner from a unit of farmland, especially under conditions of low levels of technological inputs and marginal lands. The most common definition of agroforestry is “Agroforestry is a land use system in which woody perennials (trees, shrubs etc.) are grown in association with herbaceous plants (crops and pasture) or livestock in spatial arrangement, in a rotation or both. There are both ecological and economical interaction between trees and others components of the system (Lundgren 1982). On the basis of nature of components following common Agroforestry systems/practices are prevailing in different agro-ecological regions of India:

1. Agri-silviculture (trees + crops)
2. Boundary plantation (trees on boundary + crops)
3. Block plantation (block of trees + block of crops)

4. Energy plantation (trees + crops during initial years)
5. Alley cropping (hedges + crops)
6. Agri-horticulture (fruit trees + crops)
7. Agri-silvi-horticulture (trees + fruit trees+crops)
8. Agri-silvipasture (trees+crops + pasture or animals)
9. Silvi-olericulture (trees + vegetables)
10. Horti-pasture (fruit trees + pasture or animals)
11. Horti-olericulture (fruit trees + vegetables)
12. Silvi-pasture (trees+pasture/animals)
13. Forage forestry (forage trees + pasture)
14. Shelter-belts (trees + crops)
15. Wind-breaks (trees + crops)
16. Live fence (shrubs and under- trees on boundary)
17. Silvi or Horti-sericulture (trees or fruit trees + sericulture)
18. Horti-apiculture (fruit trees + honeybee)
19. Aqua-forestry (trees + fishes)
20. Homestead (multiple combinations of trees, fruit trees, vegetable etc).

Important Agroforestry Systems in different regions of the country

Eastern-Himalayas

Among several shade tree species in large plantation areas of eastern Himalayas, alder (*Alnus nepalensis*) is most abundant and preferred tree, which is a non-leguminous nitrogen fixing tree. Besides large cardamom, many food crops like maize, millet, potato, barley, chillies and colocasia are grown with alder. The tree not only provides shade to arable crops, timber and fuelwood but also ameliorates the soil and protects it from erosion on hilly slopes. A yield of 400-500 kg ha⁻¹ of cardamom has been reported in a year under shade trees. If a village with 100 families could set aside about 120 ha of land to grow alder trees, all families would be able to get sufficient fuelwood every year and at the same time raise crops under the alder in about 30 ha area every year. Cultivation of coffee, ginger, cardamom, turmeric and medicinal plants under the shade of naturally growing trees in Meghalaya is one of the best examples of successful combination of trees with annual crops. Department of Agriculture in Mizoram has developed its own contour trench-farming for jhum areas on hills where top portion is of undisturbed forest, middle portion is with horticultural crops and down the hill, terraced rice is cultivated with pineapple and grasses on contours. Many species of bamboo,

palms (coconut, arecanut and species of *Licuala*, *Phoenix*, *Wallichia*, *Corypha*, *Caryota*) and rattans (*Calamus* spp.) are cultivated widely in north-eastern areas as mixed or boundary plantations. Pasture in forests is also a common practice. In Sikkim on hilly areas, Nevaro (*Ficus auriculata*) based silvipastoral systems have shown production potential of 15.6-51.6 t ha⁻¹ annually and goats could be reared successfully.

It has been found that sericulture based system is highly relevant for these areas. Mulberry with frenchbean-groundnut followed by mustard is a profitable cropping system with mulberry, guava/lemon/pear and pineapple in paired rows and grasses on the bunds is an ideal system for silk production and additional income from fruits and cattle rearing. Padi-cum-sericulture is said to be more viable as the cash returns are more frequent.

Shifting cultivation or slash and burn agriculture (locally called as Jhum) is the main form of agriculture in the hills of North Eastern region of India. Due to mountainous terrain, settled cultivation constitute only a small proportion of the total cultivated land which is confined mostly to Assam and valley lands in the hill states. Shifting cultivation in the region is a complex system with wide variation that depends upon the ecological variation in the area and cultural diversity among various tribal clans. However, the basic cropping practice has many similarities. Shifting cultivation in its traditional form was not so harmful when the jhum cycle was 15-20 years. But with reduction of jhum cycle, it has become environmentally destructive and a faulty land use practice having very low output-input ratio (Tripathi and Barik 2003). The primary reason may be increase in population which led to increase demand of food, ultimately resulting in reduction of jhum cycle to 2-4 years. Such faulty land use led to severe land degradation due to soil erosion and associated factors such as reduction in soil organic carbon, nutrients etc., which resulted in decrease in crop yield. There is decline of forest cover due to shifting cultivation in the NEH region although the degree varies from one state to the other. Total area under Jhum also varies among the different hill states. According to the Wastelands atlas of India (2011), maximum area under shifting cultivation is in Nagaland followed by Arunachal Pradesh. However, Arunachal Pradesh shows maximum increase in jhum land during the period of 2005-06 to 2008-09. On the other hand, on considering national scenario, NEH of India represents 80% of the jhum lands, which is a matter of serious concern.

Western Himalayas

In the Western Himalayas, 60 to 70% requirement of the firewood is met from the arboreal components and several MPTs along the bunds of agricultural lands or scattered trees on the pasture lands were developed depending upon the needs, economics and environmental status of the land. High rate of net primary

productivity has been reported in agri-hortisilvicultural systems ($206 \text{ t ha}^{-1} \text{ yr}^{-1}$) or agri-horticultural systems ($23 \text{ t ha}^{-1} \text{ yr}^{-1}$) and the species number in these systems is as high as 15 tree species. Generally 50 to 100 trees are planted in a hectare for fulfilling a part of the fodder and fuelwood requirements. *Grewia optiva*, *Celtis australis*, *Bauhinia variegata*, *Albizia chinensis*, *Bombax ceiba*, *Melia azedarach* and *Toona ciliata* are common MPTs while plum (*Prunus domestica*), apricot (*P. armeniaca*), peach (*P. persica*), almond (*P. dulcis*) and pear (*Pyrus communis*) are common fruit trees of these systems. Hedge-row intercropping is feasible and important on sloping hilly lands when pruned biomass during cropping season can be used for fodder and fuelwood.

Indo-Gangetic Plains

Indo-Gangetic plains (IGP) comprises of four agro-climatic zones viz. Lower, Middle, Upper and Trans Gangetic plains covering West Bengal, Bihar, Uttar Pradesh, Delhi, Uttarakhand, Chandigarh, Haryana, Punjab and Rajasthan states. It's having 169 districts with total geographical area of 43.70 million ha. The Indo-Gangetic plains are one of the most populous region of the country. The area of the IGP is nearly 13 % of the total geographical area of the country, and it produces about 50 % of the total food grains to feed 40 % of the population of the country. Rice-wheat system is very common and popular system of the region. The continuous cropping of rice-wheat system degraded soil health dramatically over the years. Hence incorporation of trees in agriculture would be better option to improve soil as well as livelihood of the famers in IGP.

Agriculture is the major enterprise of the region that is most vulnerable to climate change particularly smallholder farmers because they do not have adequate resources to adapt to climate change. While agroforestry may play a significant role in mitigating the atmospheric accumulation of greenhouse gases (GHG), it also has a role to play in helping smallholder farmers adapt to climate change. Since agroforestry systems fulfill both the productive and service role. In productive role, the agroforestry system provides pulpwood, fuelwood, timber, fodder and fruit. Of the service functions, that of soil conservation is without doubt the most important. Besides that, trees in agroforestry system produces adequate amount of leaf litter that is sufficient to maintain soil organic carbon, if litter is not removed from the field. These are the reasons for recognizing agroforestry as a viable alternative to prevent and mitigate climate change. A considerable proportion of agroforestry area located in IGP and some of the promising tree species like poplar, eucalyptus, Melia, mango, shisham and babul are very common on farmer's fields. The farmers of Punjab, Haryana and western Uttar Pradesh are commercially growing eucalyptus and poplar under agroforestry system that attracted the timber market in these areas.

Agroforestry in Humid and Sub-humid Region

In Tripura tree component is used along with livestock and poultry component, whereas in irrigated areas fish component is also incorporated. Agrisilviculture is common in Raipur and Ranchi areas. *Acacia nilotica*, *Terminalia arjuna*, *Butea monosperma*, *Albizia* spp. are grown in Raipur area while *Zizyphus mauritiana*, *B. monosperma*, *Aegle marmelos*, *Mangifera indica*, *Schleichera oleosa* (Kusum) in Ranchi area. Homestead Agroforestry is also being practised using *Gmelina arborea*, *Artocarpus heterophyllus*, *Madhuca latifolia*, *Zizyphus mauritiana* etc. In Bhubaneswar area agrisilviculture (*Cocos nucifera* for boundary plantation, block plantation of *Casuarina equisetifolia*, *Anacardium occidentale*) and homesteads are being practised. At both the centres (Raipur and Ranchi) *Gmelina arborea* is also used as timber while *Tectona grandis*, *Acacia nilotica* are used as timber trees at Raipur and *Shorea robusta* at Ranchi. *Leucaena leucocephala* is used at Raipur and Ranchi for fodder and *Pongamia pinnata*, *Acacia nilotica* and *Dalbergia sissoo* are also used as fodder at Raipur. *Mangifera indica* and *Artocarpus heterophyllus* are grown for fruits. Other fruit trees are *Moringa oleifera* and *Syzygium cumini*, in Raipur area and *Psidium guajava*, *Carica papaya* in and around Ranchi. *Terminalia arjuna* for raising silk worm and *Butea monosperma*, *Schleichera oleosa* for Lac cultivation are being used by the farmers in Ranchi area.

Agroforestry in Arid and Semi-Arid Regions

In most of the arid region of the north-western India, Khejri (*Prosopis cineraria*) based silvi-agriculture system is prominent. Almost in all the fields' most useful khejri trees and small fruit yielding *Zizyphus nummularia* are found grown in association with rainfed crops. *Zizyphus nummularia* is used for its leaves as fodder for camel and goats and berries for edible purposes. *Acacia tortilis*, *A. nilotica*, *A. senegal*, *A. leucophloea*, *Capparis decidua*, *Tecomella undulata*, *Salvadora persica* and *S. oleoides* are other common trees found on various grazing lands or as sand stabilizers. *Calligonum polygonoides* is another interesting bush in Bikaner region. *Lasiurus indicus* and *Cenchrus ciliaris* are prominent grasses in grazing fields as well as in sand dunes. In Arid regions of Western India, introduction of compatible fuel, fodder and fruit trees in pastures as in agricultural fields acts as an insurance against frequent crop failures, and trees play a pivotal role towards peoples' survival and sustenance in such fragile ecosystems.

In Central India, *Dalbergia sissoo*, *Acacia nilotica*, *A. eburnea*, *A. leucophloea*, *A. catechu*, *Albizia lebbeck*, *Azadirachta indica*, *Butea monosperma*, *Pongamia pinnata*, *Holoptelea integrifolia*, *Balanites roxburghii* and *Dichrostachys cinerea* form important constituents of a silvi-pastoral system.

In semi arid regions of Peninsular India the systems are more complex as the problem of frost does not exist, therefore, a vast number of trees (both fruit yielding and MPTs) exist on agricultural fields. *Borassus flabellifer*, *Tamarindus indica*, *Acacia leucophloea*, *A. catechu*, *Casuarina equisetifolia*, *Cassia siamea*, *Eucalyptus tereticornis*, *Albizia lebbbeck*, and many others are frequent trees on farms. *Leucaena leucocephala* has also been adopted as a common hedge-row-crop in many areas.

Agroforestry Systems for Coastal and Island Regions

Low lying water logged marshy areas, flood plains, and ill-drained lands are the common features in the coastal areas swamps and river banks are occupied by the mangroves and associate halophytes. Other natural vegetation includes evergreen, semi-evergreen and deciduous forests on uplands and grazing lands in pockets. Plantation crops integrated with livestock and poultry and rice fields are main features of this region.

The systems and practices of Agroforestry range from apparently 'simple' forms of shifting cultivation and farming in forests to sophisticated hedgerow intercropping systems, from systems involving sparse stands of trees on farm lands to high density, complex multistoreyed home- gardens of lowland; and from systems in which trees play a predominantly 'service' role (e.g. shelterbelts) to those in which they provide the main commercial product (e.g. intercropping with plantation crops). Though many scientific inputs are given to plantation crops and multiple cropping systems are adopted but quite large areas under coconut plantation are still neglected and remain open for grazing. These areas may be brought under multistoreyed cropping systems. Spices like clove and cinnamon may be planted as middle storey crops and pineapple or forage grasses like hybrid napier (*Pennisetum purpureum*), kazungula (*Setaria anceps*) and guinea (*Panicum maximum*) and legumes like *Stylosanthes guianensis* or industrial grasses like lemon grass (*Cymbopogon fulvus*) may be grown as cover crops. Rubber and red oil palm plantations may also be integrated with other spice or forage crops particularly the legume covers. Monoculture of plantation crops should be discouraged and a multi- storeyed plantation system should be raised as has been demonstrated in Jirka Tang Farm in Andaman where even the forest-trees are retained in multi-storeyed plantations and almost all plantations including spices, coffee and fruit trees have been accommodated as under-storey crops.

Purpose of growing trees by different categories of farmers

Relationship of man with trees and the land use systems is as ancient as the very evolution of human civilization and use and domestication of plants. Tree-based farming systems integrating trees into agriculturally productive landscape is an

age old practice in India. Trees provide farmers with marketable products such as timber, building poles, firewood, animal fodder, fruits, medicine all of which earn extra income. India is a land of small farmers. According to Agricultural Census 2000-01, there were an estimated 98 million small and marginal holdings out of around 120 million total land households in the country. The share of marginal and small farmers accounted for around 81% of operational holdings in 2002-03. Recent data for 2005-06 shows that the share of small and marginal farmers in land holdings was 83% (Chand et al, 2011). Generally, small and medium farmers grow the trees on their field for domestic purposes like fuelwood, fodder, timber etc. The trees normally occur either on field bund or scattered in the field. The farmers manage the tree by their own ways. But in case large farmers, commercial plantation of eucalyptus, poplar, gmelina, casurina, Teak, ailanthus, aonla, mango, sapota can be seen in some part of the country.

Trees have both productive and protective role in agriculture system. In productive role, it enhance the productivity of lands and help to meet the increasing demands of human and livestock.

In addition to food security, the small and marginal farmers are growing trees for livelihood security and additional returns. Many agroforestry technologies and systems have been developed for different agro-ecological regions of the country and in addition to providing higher returns these systems also ensured livelihood security and a cover against crop failure due to climatic aberrations particularly under arid and semi-arid regions of the country. Few of the important activities and purpose for integrating trees in the land use systems by the farmers for livelihood security are:

Lac cultivation

India is the largest producer of lac in the world. The mean lac production in the country was 20,640 tons (2003-04 to 2007-08). The average income from lac cultivation was found to contribute 26.4 % of the farm income in Jharkhand and act as subsidiary crop for the growers for meeting cash expenses towards family needs and cash purchase for their house hold requirements. Conventional tree hosts of lac like ber (*Zizyphus mauritiana*) and palas (*Butea monosperma*) can easily be integrated in bunds of cropped fields. Other quick-growing hosts like *Flemingia semialata* hold potential for integration in farming system models.

Sericulture

All the four known varieties of silk, viz., Mulberry, Tasar, Eri and Muga are cultivated in India and India ranks second in world's silk production. The plants

used in the silk production, such as *Terminalia tomentosa* (asan), *T. arjuna* (arjun) and *Shorea robusta* (sal) for tasar insect; the commonly used *Morus alba*, *M. indica*, *M. serrata* and *M. latifolia* for mulberry insect; can be included in the agroforestry models.

Apiculture

India produces about 70,000 t of honey, out of which 25-27,000 t is exported to various countries. India has four of the six reported honey bee species; *Apis dorsata*, *A. cerana indica*, and *A. mellifera* (introduced) are mainly used in India for honey production. Honey bees are not only important for their honey but are also of paramount importance to agriculture production and plant diversity, as pollinators. There had been a world-wide decline in the population of honey bees and in India the decline had been estimated at >40% during the past quarter century. The promotion of apiculture will not only provide additional income to the farmers but will also results in other benefits to the agricultural production due to their role as pollinators. A number of agroforestry tree species have been identified which can act as host species for honey bees and there is ample scope for inclusion such trees in different agroforestry models to sustain round the year honey production.

Gum and Resin

Gums and resins form an important group of non-wood forest products. The industrial applications of gum and resin have expanded tremendously in recent years. They are used in many unrelated industries such as paper, textile, petroleum, pharmaceutical, cosmetics, food, varnishes, lacquers and soaps. Even though gum and resins is produced by a large number of plants, their commercial exploitation is restricted to members of the Leguminosae, Sterculiaceae, Combretaceae, Pinaceae, Dipterocarpaceae, Burseraceae and Umbelliferae. Indonesia, India, China and Sudan are among the World's major producers of gums and resins. India annually produces about 281,000 t which includes about 224,000 t of gums, 55,500 t of resins and 1,500 t of gum-resins. India is traditionally largest producer of guar gum and karaya gum. Gum yielding trees species such as *Acacia senegal* (yielding gum Arabic) and *Boswellia serrata* (yielding salai guggul) are potential species for agroforestry models and needs to be promoted on large scale to provide sustained income and livelihood security to the resource poor rural masses.

Agroforestry-Environment linkages

The role of agroforestry in protecting the environment and providing a number of ecosystem services is promoted as a key benefit of integrating trees into farming systems. As traditionally employed, these benefits were intuitive to the farmers

and landowners that managed agroforestry systems, although the scientific evidence to support such benefits is only now coming to light. The impact of agroforestry on the environment occurs at a range of spatial and temporal scales; from fine-scale impacts on soil structure and quality to impacts on the environment and society at regional or global scales.

Agroforestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification and buffering of farming systems. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years. First, their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during droughts. Second, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years. Third, tree-based systems have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems. Finally, tree-based production systems often produce crops of higher value than row crops. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with climatic variability. Another important agroforestry system which is well-known to buffer against production risk associated with climate variability is the parkland or scattered tree systems. Shelterbelts and windbreaks is well known practices, which modify the micro-climate and help in crop production through reducing moisture loss particularly dry areas.

Control of soil erosion

Purposefully planted cover can take several forms that can differ in their ability to counter soil and water loss. Vegetative cover is the key to arrest runoff and soil loss. It has been estimated that soil erosion is accelerated to more than 900 times when tree plantation were clean weeded or the litter was burnt. In a semi-arid Alfisols degraded land established pastures reduced runoff to 26% and soil loss to 8% (Pathak, 2000). In another study agroforestry system recorded runoff 2.7%, soil loss 0.54 tonnes ha⁻¹ year⁻¹, N loss 2.1 kg ha⁻¹ year⁻¹ and K loss 0.7 kg ha⁻¹ year⁻¹ with mean monsoon season rainfall of 899 mm compared with runoff 25.4%, soil loss 3.21 tonnes ha⁻¹ year⁻¹, N loss 12.5 kg ha⁻¹ year⁻¹ and K loss 4.3 kg ha⁻¹ year⁻¹ from the field crops raised under same condition (Grewal et al., 1995). By alternate land use systems like silvipasture, agrisilviculture and agrihorticulture, the productive and protective benefits from watershed management are considerably higher than the investment, benefit: cost ratios ranging from 1.92: 1 to 7.1:1 with 48 to 99 % reduction in runoff and 81 to 98% soil loss besides the check of out migration of population from 26.6% before the implementation of WSM programme to 9.3% during the project period (Samra et

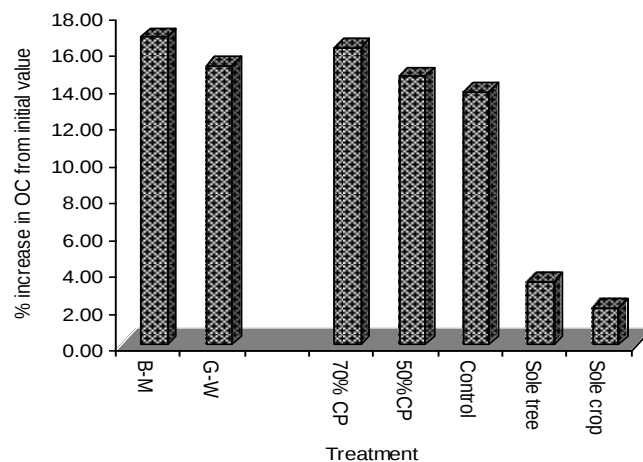
al., 1999). On sloppy lands contour hedgerows have consistently been demonstrated to be highly effective in controlling soil erosion even in as little as 18 months (Lal, 1989; Maclean et al., 1992). The woody hedgerows provide a semi-permeable barrier to surface movement of water, while mulch from the trees reduces the impact of raindrops on the soil and minimizes splash and sheet erosion (Young, 1989).

Maintain soil fertility/organic matter level

The primary objective of soil conservation is to improve /maintain soil fertility. To achieve this, control of erosion, maintenance of organic matter, maintenance of physical properties, organic matter addition, maintenance of nutrient is necessary. In this way agroforestry system constitute sustainable land use and help to improve soils in a number of ways. Some of these beneficial affects are apparent in experiments carried out in different parts of the country. Tree crowns protect the soil from the impact of raindrops and create a specific microclimate in the particular area (Pradhan, 1973).

Agroforestry practices play an important role in improving the fertility of the soils. Increase in amount of nitrogen and phosphorus and other macro and micro-nutrients are reported under the growth of 14 yr. old plantation of *Prosopis cineraria* as compared to a bare site of *Prosopis juliflora* of the same age (Shankarnarayan, 1984). Samra and Singh (2000) observed an increase in soil organic carbon status of surface soil 0.39 % to 0.52% under *Acacia nilotica* + *Sacchram munja* and 0.44% to 0.55% under *Acacia nilotica* + *Eulaliopsis binata* after five years and suggested that *Acacia nilotica* + *Eulaliopsis binata* are conservative but more productive and less competitive with trees and suitable for eco-friendly conservation and rehabilitation of degraded lands of Shivalik foot hills of subtropical northern India.

An experimental evidence under agrisilvihorticultural system (aonla+ leucaena + blackgram) in rainfed conditions showed that after nine years organic carbon was increased by 65 to 109.4% under below canopy and 28.1 to 62.5% under open canopy as compared to initial value (0.32%). The complete falling of senesce aonla leaves during spring season add lot of organic matter which is mostly limited to below tree canopy (Ram Newaj et al., 1999). An increase in organic carbon, available N, P and K content in Khejri based silvipastoral system over no-Khejri soil, advocating retention/plantation of Khejri tree in pasture land to get higher fodder production and to meet requirement of food, fodder, fuel and small timber (Jaimini et al., 2006). Ram Newaj et al. (2008) observed that in agrisilviculture growing of *Albizia procera* with different pruning regimes, the organic carbon of the soil increased by 13-16% form their initial values under differ pruning regimes which was five to six times higher than growing of either sole tree or sole crop (Fig. 1).



Note: B-M= Blackgram-mustard, G-W=Greengram-wheat, CP= Canopy pruning

Fig. 1 Increase in soil organic carbon under agrisilviculture and pure tree and pure crop from initial value after three years

Biological reclamation of saline and alkali soil

In order to rehabilitate salt-affected lands, appropriate tree planting techniques and choices of tree species are very crucial for better initial establishment of saplings. Since alkaline and saline soils differ from each other, methods of working the soils will also be different. For example, in alkali soils a hard kankar layer of calcium carbonate is generally found at a depth of about 1.25 to 1.5m. This layer acts as a barrier for root penetration. The layer, therefore, has to be broken first to allow proper development of roots. However, saline soils do not require such preparation, as they do not have any such barriers. These require special techniques of afforestation so that salt contents in root zone are minimized.

The ideal planting method for alkali soils should provide a favorable soil environment such as by breaking the hard kankar layer, replacement of exchangeable sodium and additional nutrition of tree species for optimum root growth. Keeping this view in mind, pit-auger-hole technique of tree plantation was developed by the scientists of Central Soil Salinity Research Institute (Dagar et al., 2001; Singh and Dagar, 2005; Dagar, 2012). In this planting method, auger-holes of 15-20 cm diameter are made to pierce the hard kankar layer up to 150 - 180 cm deep, with the help of a tractor-mounted auger after digging pits of 35 cm x 35 cm. Auger holes are refilled with original soil, 3 kg gypsum, 8 kg FYM, 10 g $ZnSO_4$, and small quantity of insecticide to take care of termites. Sodicty tolerant tree saplings of 6-9 months old are planted in the refilled pit-auger holes followed by irrigation with buckets. Two to three irrigations are immediately needed for

establishment of saplings. This method enables the plant roots to grow at a faster rate towards deeper soil layers where sufficient moisture and nutrients are available in alkali soils.

The choice of species for alkali lands is determined by the ability of tree species to survive and withstand adverse conditions of excess sodicity. Tolerant tree species overcome high concentrations of sodicity by different regulatory mechanisms. There are very few wild plant species, which are able to grow on highly sodic soils (pH >10). On the basis of experiments conducted on highly alkali soil *Prosopis juliflora*, *Acacia nilotica*, *Casuarina equisetifolia*, *Tamarix articulata*, *Eucalyptus tereticornis* and *Parkinsonia aculeata* demonstrated a higher tolerance. The biomass of 7 years old *T. articulata*, *A. nilotica* and *P. juliflora* was 97.3, 69.8 and 51.3 t ha⁻¹ respectively. Singh et al (2008) reported 19.22 to 56.5 t ha⁻¹ yr⁻¹ -dry biomass from different species raised on high sodic soil (Figure 2).

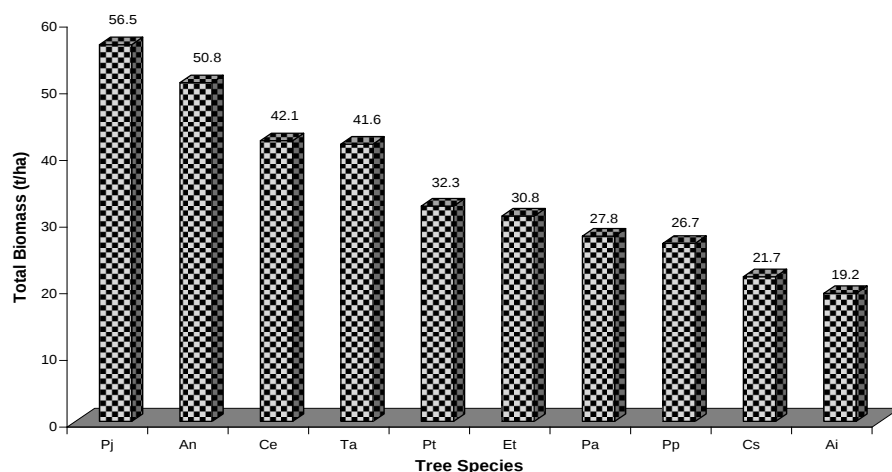


Figure 2. Above-ground air-dried biomass (t/ha) of different trees grown in sodic soil

Pj=*Prosopis juliflora*, An= *Acacia nilotica*, Ce= *Casuarina equisetifolia*, Ta= *Terminalia arjuna*, Pd=*Pithecellobium dulce*, Et= *Eucalyptus tereticornis*, Pa= *Prosopis alba*, Pp= *Pongamia pinnata*, Cs= *Cassia siamea*, Ai= *Azadirachta indica*.

Shelterbelts and windbreaks

Shelter belts and wind breaks are effective in control of wind erosion in arid region. Development of wind breaks across the wind direction has been shown to reduce wind velocity by 20-46% and soil loss by 76%. Usually three row wind breaks with central row of tall trees like *Albizia lebbek*, with single row of branched trees like *Acacia tortilis*, *Cassia siamea* or *Prosopis juliflora* on other sides of *Albizia lebbek* are very effective. Besides reducing wind speed and

evaporation, shelterbelts are useful in checking wind erosion and fertility loss from the agricultural fields. In western Rajasthan, three row shelter belts of *C. siamea* – *A. lebbek* – *C. siamea* is highly effective in reducing wind speed and loss of nutrients.

Agroforestry technologies

India has been at the forefront of Agroforestry research. Although Agroforestry research in the ICAR system and other Indian institutes and universities has been in progress since early 1950s, the Council launched the All India Coordinated Research Project on Agroforestry in 1983. Presently, 36 Centres (11 ICAR Institutes + 25 SAUs) representing all agro-climates in the country are involved. The National Research Centre on Agroforestry, one of the ICAR Centres, was established at Jhansi in 1988. The Indian Council of Forestry Research and Education (ICFRE) also support Agroforestry research in education in various parts of the country. A number of State Agriculture Universities (SAUs) are also having focused research activities and education in the field of Agroforestry. Private sector initiatives in Agroforestry such as those by WIMCO, BAIF, IFFDC, ITC are worth mentioning. In all, more than 2000 scientists and technicians are engaged in Agroforestry research, development and education in the country. Since agroforestry research is site specific/region specific that's why the technology developed in agroforestry vary in different agro-climatic zones. Based on promising tree species for a particular agroclimatic zone, the agroforestry system is characterized for different agroclimatic zones. Brief summary of important agroforestry technologies is given in Annexure I. Some of the agroforestry technology developed in different agroclimatic zones are described below:

Poplar based Agroforestry system

Poplar is the most successful tree species of agroforestry in Indo-gangetic region. Five poplar clones viz., PL-1, PL-2, PL-3, PL-4 and PL-5 have been recommended for the region. An increase in volume (m^3) ranging from 32 to 35 per cent was observed in the above-mentioned recommended clones compared to G-3 clone taken as a control which ultimately leads to better economic returns. The studies have revealed that during the first two years of plantation, most of the crops performed well in poplar. However, after two years, when competition for growth resources like light, moisture and



nutrients become severe, the cultivation of kharif crops except turmeric is not economical, whereas in the rabi season, wheat and berseem crops gave good yields up to maturity of poplar due to reduced competition for growth resources on account of leaf fall in the winter season. The yield of crops during both the seasons increased with increase in poplar spacing. Regarding agronomic practices of wheat, use of 25 per cent higher seed rate and 25 per cent less fertilizer doses after 4 years of poplar plantation when the wheat yields decrease by more than 50 per cent, has been recommended. Among the wheat varieties, WH542, WH896, PBW343 and WH711 varieties gave higher yields than other varieties.

Alder - large cardamom based agrisilviculture

The first inhabitants of Sikkim – the Lepchas collected capsules of large cardamom from natural forests. New plantations and large patches of large cardamom based agroforestry systems have been converted in to monoculture of N_2 fixing actinorhizal *Alnus nepalensis* as shade tree (Sharma et al., 1998). Other common trees are *Schima wallichii*, *Engelhardtia acerfolia*, *Eurya acuminata*, *Leucosceptum canum*, *Maesa chisia*, *Symplocos theifolia*, *Ficunemorialis*, *F. hookeri*, *Nyssa sessiliflora*, *Osbeckia paniculata*, *Viburnum cordifolium*, *Litsaea polyantha*, *Macaranga postulata*, etc. Thus it is conducive to conservation of tree biodiversity in north eastern region.

Large scale land use transition for maximizing the benefits to meet the rising demands for food and other ecosystem services for the well being of the societies has been the main problem confronting sustainable development in the mountain areas. Agroforestry is one of the favoured land management systems in the mountains. This paper analyses the role of traditional large cardamom (*Amomum subulatum*) agroforestry system on enhancing the ecosystem services in the Eastern Himalayas. The large cardamom based agroforestry system is observed to accelerate the nutrient cycling, increases the soil fertility and productivity, reduces soil erosion, conserves biodiversity, conserves water and soil, serves as carbon sink, improves the living standards of the communities by increasing the farm incomes and also provides aesthetic values for the mountain societies. The cardamom agroforestry stored 3.5 times more carbon than the rainfed agriculture showing potential mitigation possibilities of the agroforestry by sequestration of the atmospheric carbon. The agroforestry is an efficient management system where ratio of output to input is more than 13 compared to rainfed agriculture. Cost benefit analysis showed that the cardamom agroforestry is profiting the farmers by 5.7 times more compared to the rainfed agriculture. This agroforestry system is a unique example of the ecological sustenance and economic viability for the mountain peoples while providing goods and services to the downstream users. In the large scale land use change role of the cardamom agroforestry seems quite promising for ecological and economic sustainability.

Large cardamom agroforestry is almost a closed system that does not depend on the external input. The system requires about 800 to 1000 kg/ha of raw fuel-wood for curing the capsules that can be managed from the shade trees within the agroforestry. The annual production of woody biomass in cardamom based agroforestry ranges between 4.5 to 5.5 t/ha which is more five times of fuel wood requirement for curing (Sharma et al., 2000). The share of gross income from large cardamom (Rs. 27 crores) was next to cereals over Sikkim state income from all crops for the year 1995-96. The benefit –cost ratio is more than 6 from fourth year onwards.

Prosopis cineraria based agroforestry for hot arid region of Gujarat and Rajasthan

The increasing demand of fodder and fuel wood as a function of increasing human as well as livestock population in the region emphasized the need of more diversified production system. However, forest cover in the dry areas is very poor and therefore emphasis is laid on integrating trees in agricultural land to intensify the traditional production system and to meet the increasing multiple demands. This study on the effect of varying regimes of *Prosopis cineraria* (khezri) and *Tecomella undulata* (rohida) and the soil plant interaction was initiated in 1991 with 1666, 833 and 417 stem ha⁻¹ of *P. cineraria* and different agricultural crops. Because of general practice of crop rotation, the intercrops grown were *Vigna mungo* (L.) (mungbean) in 1999, 2000 and 2003 and *Pennisetum glaucum* (L) R. Br. (pearlmillet) in 2001. Crops were sown and harvested in rainy season (July to October) and rainfed condition.

Outputs of crop yield and tree growth and biomass suggested that optimum tree density, which provided highest crop production decreased with tree size/ age i.e., 417 trees ha⁻¹ (4 m x 6 m), 278 trees ha⁻¹ (4 m x 9 m) at 6 and 7 years, 208 trees ha⁻¹ (8 m x 6 m) at 10 year and less than 208 trees ha⁻¹ at 11 year of age and above. The result indicated bio-economic benefits of optimum tree density of traditional practices of integrating trees in farming system in arid zones.

In general people of Indian desert does not plant *P. cineraria* plants on their farmland rather protect and take care of randomly growing tree or seedlings regenerated on their farmlands. Maintaining optimum densities of trees increased crop yields by 10-15% as compared to the sole crop without tree. The result indicated bio-economic benefits of optimum tree density of traditional practices of integrating trees in farming system in arid zones. In addition, *P. cineraria* provides fruit of 350 –1040 g tree⁻¹ used as vegetable. In addition, *P. cineraria* provides utilizable biomass of 19.96 tones ha⁻¹ including leaf fodder of 0.85 tones ha⁻¹ per year at 12 year age (208 tree ha⁻¹).

Aonla based agroforestry system for semi-arid region

Rainfed agriculture contributes, 44% of food production from 68% of total arable land and supports 40% of the population. Most of the coarse cereals except maize are grown in rainfed regions. These regions support 84% groundnut, 91% pulses, 55% rice, 68% cotton and 22% wheat production. Productivity of rainfed crops continues to be low; it is one half to one third of that obtained with irrigated crops. This necessitated the evolution of suitable land use systems for such lands involving perennial component which are drought tolerant and yield quick return with higher economic value. Aonla (*Emblica officinalis* Gaertn.) is the best option among the semiarid and arid fruit crops and has all required qualities for rainfed areas. Keeping the above point in view a field experiment on “Aonla based

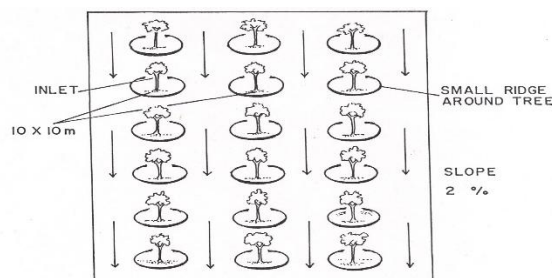
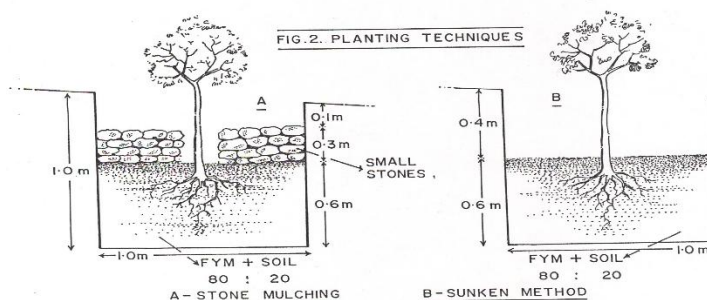


FIG-1. METHOD OF INSITU WATER HARVESTING TECHNIQUES IN AONLA BASED AGRIHORTICULTURE SYSTEM UNDER RAINFED CONDITIONS



Agroforestry” was initiated at NRC for Agroforestry in two phases. In first phase, evaluation of different varieties was taken up during 1989 and in second phase, after evaluation of a high yielding and best suited variety under agroforestry in the rainfed areas of marginal lands, the study on other aspects like; in -situ moisture conservation, soil improvement, economics, nursery techniques for multiplication, disease and pest management were initiated during 1996 to standardize the technology for target users.

In agri-silvi-horti-culture system, inclusion of subabul not only provide fuel and fodder but also add leaf litters as well as fixes nitrogen into the soil. Addition of organic matter through leaf litter of trees and



crop reduces in the soil, increase porosity and induce infiltration rate of soil and it helps in reducing the runoff and soil loss. Increase in 68% organic carbon in 9 years of experimentation proves the soil nutritional buildup.

In-situ moisture conservation techniques such as sunken method of planting, stone mulching, sunken method of planting in association with deep tillage in rainfed of marginal lands where moisture stress is most serious problem in crop cultivation may help to conserve rainwater during excess rainfall years. Otherwise, precious amount of water is lost through runoff where in-situ moisture conservation techniques are not being adopted. Deep tillage breaks hard layer of soil and facilitate water penetration into deeper soil layer where moisture can be retained for quite long time, which may be beneficial in the long run to the fruit trees and crop as well.

Fruit bearing in aonla started after 4 years of plantation. The fruit yield during initial years was low and it increased with subsequent increase in age and growth of fruit trees. At the age of 6th year, on an average, the fruit yield from a plant was 93 kg. Among different varieties, var. Kanchan was superior in terms of fruit yield and it gave 76 % higher yield than second higher yielder var. NA 7. Among different spacing, total fruit yield was higher in 5 m x 6 m spacing than 10 m x 6 m due to higher number of plants per hectare during initial years. When the tree were fully grown, this spacing was disfavored the tractor operation and cultivation of crop. Thus, 10 m x 6 m proved as ideal spacing among these and it was considered for calculating the yield and economics of the system. The fruit yield of aonla varied year to year which clearly indicated that in alternate year the fruit yield was higher and it also has a relation with rainfall received during preceding year. Besides fruit yield of aonla, 256 kg grain was obtained from blackgram per hectare every year.

Introduction of leucaena in the system provided organic matter in the form of leaf litter and it also fixes atmospheric nitrogen in the soil. Leucaena was cut twice a year and it provided on an average 1325kg fuel wood and 799kg leaves ha⁻¹ every year (Table 1). The leaves of leucaena were utilized as mulch to minimize moisture loss from soil during summer, which is very beneficial in alfisols in rainfed areas.



Besides fuel and fodder yield from leucaena, it also help in improving soil fertility. Soil organic carbon and total N was increased by 68 % and 42 % respectively during 9th year of experimentation and during 11th year of

experimentation, soil organic carbon, total N and available K was increased by 77%, 60% and 15 % respectively compared to the state before experimentation. The soil pH was lowered down by 0.6 units after 11th year of experimentation.

The survival of aonla plant was 96% under moisture conservation techniques and 88% in traditional method of planting. The growth of fruit trees was also better in moisture conservation techniques than traditional method of planting. Moisture conservation techniques had conserved 10 to 20% more moisture in their pit area compared to traditional method of planting.

Aonla gave 481.95 kg ha⁻¹ at age of four years and fruit yield increased gradually in 6th and 7th year. In 7th year fruit yield from a plant was up to 75 kg and total fruit yield from a hectare of land was 3421.26 kg. Besides fruit yield, greengram produced about 145.35 kg grain every year from same unit of land. Yield reduction due to fruit trees was about 34 to 66% in different years and these amounts of yield reduction was fully compensated by the yield obtained from fruit trees. In this system, greengram being a leguminous crop fixes atmospheric nitrogen in the soil and also acts as vegetative cover to protect the soil from water erosion during rainy season.

The cost of cultivation of a hectare land in first year, which include the input cost on digging of pits, sapling, FYM, planting, aftercare and cultivation of crop was Rs.8,105 to 8,264 in various moisture conservation techniques adopted for planting and Rs. 6250 on traditional method of planting. The cost of cultivation decreased during second year and onwards because the cost of cultivation included the input required for cultivation of crop and aftercare of fruit trees only. The cost of cultivation increased subsequently with increase in input cost. The gross income from a hectare of land was Rs. 1,172 to 2,781 per year during initial year when aonla was not under fruiting. The total income from the system increased after four year when aonla started fruiting and it was Rs. 16,615 during 6th year and Rs. 44,172 in 7th year. The income obtained from aonla fruit resulted in a positive net income of Rs. 13,440 in 6th year and Rs.37, 252 in 7th year.

Adoption of technology

As against a potential of at least 10,000 ha in Bundelkhand could be reaped in the medium term of about a decade, the technology has already spread to an estimated 1000 ha based on the sample survey, off take of saplings by 110 farmers. Besides this the private nurseries in Jhansi district and the traditional nurseries of Pratapgarh have also reported to have sold saplings to the farmers in Bundelkhand region. The estimated area where the technology could be disseminated is about 0.1 million hectare with Bundelkhand region.

MPT-based black pepper based production system

Black pepper (*Piper nigrum*), is one of the important spice crop of Kerala and is traditionally grown in the homegardens usually on a wide range of support trees (e.g. Erythrina, Macaranga, Moringa, Ceiba, ailanthus etc). Pepper (var. Karimunda) was trailed on all support trees from the second year of tree planting. The trees were subjected to annual lopping during May. Farmyard manure and cow dung (each 25 kg/tree)



were applied once annually before the onset of monsoon rains. Black pepper cultivation in dense blocks was found to be a profitable and viable land use practice even for the marginal and large-scale farmers. This technology may be suitable for the warm humid tropical climate with mean annual rainfall more than 2000 mm and temperature ranges such as 38 °C (mean maximum) and 19.5 °C (mean minimum). As regards to pepper yield, *Acacia auriculiformis* proved to be the best support tree (1.98 t ha⁻¹ of dried pepper) compared to other MPTs. The second best was *Artocarpus heterophyllus*, a common species in the homegardens of Kerala but not widely used as standard for intensive pepper cultivation. The average cost of cultivation of pepper including cost of weeding, manuring, branch lopping and harvesting was around Rs. 44160 ha⁻¹. A conservative estimate suggests that the annual income from pepper was around Rs. 158000/= and Rs. 141600 ha⁻¹ respectively from *Acacia* and *Artocarpus*.

Teak based agroforestry system

Teak is one of best tree grown for timber purpose. It is more suitable for alley, bund, boundary or channel side plantation. An experiment on agri-silvi-horti-pastoral experiment involving arable crops (Sorghum, groundnut, chilli and ragi) silvicultural crop (teak), horticultural crop (papaya) and pastoral crops (subabul and grass) was initiated on red gravelly soil on Main Agricultural Research Station, Dharwad during kharif 1984 under rainfed conditions. Teak was planted at 10m and 20m between trees in row. Along the teak row, one papaya was planted between two teak plants. On either side of teak row, grass slips and subabul seedlings were planted at 60 cm apart. Both grass and subabul were harvested 4-6 time for fodder purpose leaving 15-20 cm stubble which act as 'Live Bund' to control the runoff of rain water and soil erosion. Field crops viz., Sorghum and groundnut were more suitable among other crops tried by the farmers. The fodder yield of grass and subabul were 2 tonne ha⁻¹ and 4 tonnes ha⁻¹ in 10 m spaced teak and 1 tonne ha⁻¹ and 2 tonne ha in 20 m spaced teak rows

respectively. It slope >1%, inclusion of grass or subabul should be done. Growth of teak (height and dbh) were significantly superior in teak alone as compared to teak + pasture. The estimated volume of teak was higher in 10m spaced (24.35m³/ha) as compared to 20m teak row (13.46 m³/ha). Field crop yield was reduced by more than 50 percent as compared to sole crop. The economic analysis, at the end of 22nd years agroforestry system, integration of teak and papaya with agricultural crops resulted in highest net returns (Rs.12,316/ha/yr) followed by field crop+ teak+ papaya+ grass (Rs.10,977/ha/year) and field crops+teak+papaya+subabul (Rs.9,328/ha/year) as compared to field crop (Rs.3,546/ha/year). Nutrient status (N,P,K) was increased in agroforestry system as compared to field crop only.

Adoption of technology

This technology is demonstrated in the the farmers' field under Technology Extension Project on Agroforestry – II. Planting of teak in alleys or bund planting has been adopted by the large number of farmers in transitional zone/ under irrigation withsome modification suited to their field conditions (as border planting in one/two rows along the irrigation channels). This technology has been adopted by 2-5% of the farmers.

Agroforestry potential as Climate Smart Agriculture technology

Agricultural sectors must become climate-smart to successfully tackle current food security and climate change challenges. Agriculture, including forestry and fisheries, is crucial for food security and rural incomes as well as other essential products, such as energy, fiber, feed and a range of ecosystem services. Climate-smart agriculture is a pathway towards development and food security built on three pillars:

- Increasing productivity and incomes, enhancing resilience of livelihoods and ecosystems and reducing and removing greenhouse gas emissions from the atmosphere.
- Climate-smart agriculture contributes to a cross-cutting range of development goals.
- There are many opportunities for capturing synergies between the pillars of climate-smart agriculture, but also many situations where trade-offs are inevitable.

Working at the landscape level with an ecosystems approach, combining forestry, fisheries, crops and livestock systems is crucial for responding to the impacts of climate change and contributing to its mitigation. Inter-sectoral approaches and consistent policies across the agricultural, food security and climate change are necessary at all levels. Institutional and financial support is needed for farmers,

fishers and forest dependent peoples to make the transition to climate-smart agriculture. Some effective climate-smart practices already exist and could be scaled-up, but this can only be done with serious investments in building the knowledge base and developing technology. Investments in climate-smart agriculture must link finance opportunities from public and private sectors and also integrate climate finance into sustainable development agendas.

Other potential

Agroforestry water management

Agroforestry provides opportunities to link water conservation with soil conservation. Agroforestry has both positive and negative aspects in the management of soil water. In one hand agroforestry can increase water availability to land use systems, on the other hand, tree-crop competition for water reduces the benefits of agroforestry systems particularly in semi-arid and dry sub-humid zones. However, the negative aspects can easily be overcome by reducing the effects of tree-crop competition for water by appropriate agroforestry designs. Besides, Agroforestry interventions reduce erosivity of rainfall/runoff and erodibility of soil through dissipation of rainfall energy by canopy at low height, surface litter, obstructing overland flow, root binding and improving soil physico-chemical conditions. Association of multi-purpose tree species (MPTS) with arable crops in good lands and development of tree-based agri-silviculture, agri-horticulture, silvipasture, horti-pastoral and multistoried systems on all kinds of degraded wastelands is essential for meeting requirements of the ever-increasing population and managing water and other natural resources. Agroforestry interventions based on judicious combination of forestry, horticulture, livestock and agriculture with erosion control structures, such as half moon terraces, contour bunds, grassed waterways, gully plugging and bench terracing are helpful from water conservation and production point of view. The review clearly indicates that where rainfall is over 1000 mm yr⁻¹, water competition is not often reported but tree-crop competition for water presents problems to agroforestry design in drier regions, with rainfall below about 800 mm yr⁻¹.

Vegetation extends its influence downward into the soil as well as upward into the atmosphere. In both cases, it modifies the extremes of climate, and plays a major and accessible role in hydrologic cycle. However, there is not much information available on the influence of vegetation cover on hydrological behaviour. Besides, the quantity of water retained/utilized by the important forest trees or a particular agroforestry system has not been the subject of much research. Quantification and evaluation of the important forest trees and agroforestry systems in terms of runoff, soil loss, interception of rainfall by the plants, moisture regime and

physico-chemical properties of soil is essential for understanding their influence on hydrology as well as to provide basis for the appropriate extension recommendations for different areas.

The relationship between vegetation and runoff though recognized more than 100 years back, but has not been intensively studied earlier. It was only after 1950s that the effect of vegetation on runoff, erosion, sedimentation and water yield was studied in small-forested watersheds. In fact vegetation cover influence on hydrological behaviour and water management are the most recent branches of forestry and agroforestry research and still their remains great potential. Studies such as interception by tree canopy in *Grevillea robusta* (Wallace et al., 1995); evaporation under forest canopy (Lundgren and Lundgren, 1979), soil water depletion under *Eucalyptus grandis* in Australia (Eastham et al., 1988, 1990) and a review on the water balance in mixed tree-crop systems by Wallace (1996) highlight some of the recent attempts in this direction.

Agroforestry for wasteland development

The wasteland represents degraded, unused, uncultivated and common land as (a) lands not available for cultivation, barren and unculturable wastes, (b) other uncultivated land excluding fallow, culturable waste, permanent pastures and land under miscellaneous trees, (c) fallows under unutilized lands. New obligations emerging out of the growing population demand that, to sustain production of food and fuel, each piece of land be best utilized consistent with ecology and land use capabilities. This means that even the degraded lands may be either reclaimed for agricultural purposes or put these lands under alternate land uses. Despite the availability of technical know-how for reclamation and management of all kind of degraded lands rehabilitation process for crop production is very slow. The reasons are both social and economical. At times these lands are either owned by poor-resource farmers or belong to community or government agencies. Reclamation of these lands requires additional inputs such as biological or engineering barriers for checking soil erosion, application of amendments (gypsum, press mud and pyrite in case of alkali lands) or installation of sub-surface drainage (for saline or saline waterlogged soils), use of fertilizers (including green manure), and infrastructure of farm operations. This is a costly preposition. Requirement of extra resources on recurring basis and lack of interest in development of common lands for practicing intensive arable agriculture have been the major bottlenecks for the rehabilitation of degraded lands on an extensive scale.

In some degraded ecologies such as mine-spoils and denuded mangrove areas mainly native and stress tolerant species can be used as colonizers to rehabilitate these lands. Further, in most of the arid ecologies, the groundwater is saline. In

the scenario of scarcity of good quality water the use of poor quality waters for agriculture is inevitable. Therefore, afforestation or agroforestry involving trees, grasses and low-water requiring crops (when using saline water for irrigation) is considered an ideal land use for reclamation and management of salty lands and utilization of degraded lands using saline water for irrigation.

Carbon sequestration potential of agroforestry

Agroforestry systems can be better climate change mitigation option than ocean, and other terrestrial options, because of the secondary environmental benefits such as food security and secured land tenure, increasing farm income, restoring and maintaining above ground and below ground biodiversity, maintaining watershed hydrology and soil conservation (Yadava et al., 2010). Singh and Pandey (2011) describe the agroforestry for carbon sequestration is attractive because: (i) it sequesters carbon in vegetation and in soils depending on the pre-conversion soil C, (ii) the more intensive use of the land for agricultural production reduces the need for slash-and-burn or shifting cultivation, (iii) the wood products produced under agroforestry serve as substitute for similar products unsustainably harvested from the natural forest, (iv) to the extent that agroforestry increases the income of farmers, it reduces the incentive for further extraction from the natural forest for income augmentation, and finally, (v) agroforestry practices may have dual mitigation benefits as fodder species with high nutritive value can help to intensify diets of methane-producing ruminants while they can also sequester carbon. Agroforestry enhance the uptake of CO₂ or reduce its emission have the potential to remove a significant amount of CO₂ from the atmosphere if the trees are harvested, accompanied by replanting of same and/or other area, and sequestered carbon is locked through non-destructive use of such wood. Man researchers are proved that agroforestry system are promising land use system to increase aboveground and soil C stock to mitigate greenhouse gas emissions (Sathey and Revindranath, 1998; British et al., 2012, Verchot et al., 2006 and Yadava et al., 2010). The C sequestration potential of tropical agroforestry system in recent studies is estimated between 12 and 228 Mg ha⁻¹ with a mean value of 95 Mg ha⁻¹ (Pandey, 2007). Therefore based on global estimates of the area suitable for agroforestry (585-1215 x 10⁶ ha), 1.1-1.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Albrecht and Kandji 2003).

Agroforestry has importance as a carbon sequestration strategy because of C storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. Agroforestry can also have an indirect benefit on C sequestration when it helps to decrease pressure on natural forests, which are the largest sinks of terrestrial C. Another indirect avenue of C sequestration is through the use of agroforestry technologies for soil conservation,

which could enhance C storage in trees and soils. For increasing the C sequestration potential of agroforestry systems practices such as- Conservation of biomass and soil carbon in existing sinks; Improved logging and harvesting practices; Improved efficiency of wood processing; fire protection and more effective use of burning in both forest and agricultural systems; Increased use of biofuels; increased conversion of wood biomass into durable wood products are advocated to be exploited to their maximum potential. Agroforestry thus contributes to the resilience of agriculture by adaptation and mitigation of climate change effects. In India, evidence is now emerging that agroforestry systems are promising land use system to increase and conserve aboveground and soil carbon stocks to mitigate climate change (Dhyani et al., 2009). Average sequestration potential in agroforestry in India has been estimated to be 25 t C ha⁻¹ over 96 million ha (Sathaye and Ravindranath 1998). In another estimate agroforestry contributes 19.30% of total C stock under different land uses. The potential of agroforestry systems as carbon sink varies depending upon the species composition, age of trees, geographic location, local climatic factors and management regimes. The bamboo and trees have very different sequestration patterns, but are likely to have comparable carbon sequestration capacity, as long as the bamboo is managed and the total amount of harvested fibre is turned into durable products. Tropical *Bambusa bambos* produced total above ground biomass 287 t ha⁻¹ with a mean annual production of around 47.8 t ha⁻¹yr⁻¹, almost twice that of the *Eucalyptus* clones. The total biomass of mature bamboo at 6 years is higher than that of teak at 40 years, that is, 149 t C ha⁻¹ as compared to only 126 t C ha⁻¹ for teak. Every 5 years it would produce at least 86 t ha⁻¹ biomass and sequester 43 t C ha⁻¹, almost twice as much as a teak plantation under the similar conditions. Thus, to achieve higher level of carbon sequestration, sustainable bamboo management, regular harvesting and utilization for durable products should be advocated (Rao and Saha, 2014). The growing body of literature indicates that agroforestry systems has the potential to sequester large amounts of above and below ground carbon in addition to SOC enhancement, as compared to treeless farming systems (Ajit et al., 2013).

Biofuel and bio-energy from Agroforestry

Agroforestry answers many problems that are faced by today's agriculture in terms of stability in production, regular returns, restoration of fertility, drought mitigation and environmental concerns. To meet the growing needs of energy in the country, bio-fuel and bio-energy are being emphasized through agroforestry. AICRP on Agroforestry integrated biofuel research under its umbrella since 2003. The tree borne oilseeds (TBOs) holding promise for biofuel such as *Jatropha curcas*, *Pongamia pinnata*, *Simarouba*, *Azadiracta indica*, *Madhuca spp.*, etc. are being evaluated for their potential as bio-fuels and multi-location trials for

evolving hybrids for high seed yield and oil content are going on. The promotion of bio fuels could also provide a poverty alleviation option in the rural areas. Farmers can use fallow, waste and marginally used land for growing such trees and benefit from the annual produce, which will add to their income. With the increased green cover the environment will also benefit greatly. The use of oils is also CO₂ neutral, which would mitigate greenhouse effect. However, bio-fuel research is still at the beginning with respect to genetic improvement for increasing seed and oil yield of TBOs.

In rural areas 70-80% energy comes through biomass from trees and shrubs. Due to agroforestry initiatives large amount of woods are now being produced from outside the conventional forestlands. Small landholdings and marginal farmers, through short rotation forestry and agroforestry practices are now providing the bulk of country's domestically produced wood products. *Prosopis juliflora* is the major source of fuel for the boilers of the power generation plants in Andhra Pradesh. The fuel wood potential of indigenous (*Acacia nilotica*, *Azadirachta indica*, *Casuarina equisetifolia*, *Dalbergia sissoo*, *Prosopis cineraria* and *Ziziphus mauritiana*) and exotic (*Acacia auriculiformis*, *A. tortilis*, *Eucalyptus camaldulensis* and *E. tereticornis*) trees revealed that calorific values range from 18.7 to 20.8 MJ kg⁻¹ for indigenous tree species and 17.3 to 19.3 MJ kg⁻¹ for exotics. Species such as *Casuarina equisetifolia*, *Prosopis juliflora*, *Leuceana leucocephala* and *Calliandra calothyrsus* have become prominent due to their potential for providing wood energy at the highest efficiency, shorter rotation and also their high adaptability to diverse habitats and climates. Agroforestry plantations on community land and live fence on farm boundaries have immense potential in this regards. The option of biomass based power plant where electricity generation can be aimed from crop/plant residue is yet another option.

Constraints to up scaling agroforestry

There are, however, a number of technical challenges to the introduction and expansion of agroforestry. Many are associated with misperceptions concerning the interactions between trees and crops, and most can be solved through demonstration and training. Many of the obstacles to wider use of agroforestry are related to policies. Agricultural policies often entirely ignore trees on farms, so agricultural authorities do not develop incentives for tree cultivation or include agroforestry in extension and other guidance. The availability of quality planting material is a major bottleneck in the development of agroforestry systems in the country. The lack of quality material results in poor productivity and low returns.

The lack of well-developed markets for agroforestry products, combined with the emphasis on immediate returns seen in some agriculture projects and the difficulty many farmers face in investing in activities that have a delayed financial return, force many farmers to rule out agroforestry as a viable option.

Potential for improvement

Agroforestry, like any single coping strategy, will not prove to be the silver bullet to climate change adaptation, mitigation and food security. However, agroforestry practices do have substantial potential to help smallholder farmers and pastoralists improve their well-being and the environmental sustainability of their farms and landscapes. By adopting the recommendations outlined below, we believe that agroforestry can be a cornerstone of climate-smart agriculture and contribute, as a part of larger development initiatives, to helping those who depend upon on agriculture for their livelihoods to better adapt to future climate change.

- Provide an enabling legal and political environment with an overarching national plan, appropriate institutions and effective and transparent governance structures that coordinate between sectoral responsibilities and across national to local institutions.
- Improve market accessibility and development of markets for ecosystem services to enhance income-generating opportunities provided by agroforestry. This can be done through improving infrastructure or more locally through establishing cooperatives that pool resources to access markets.
- Involve farmers and pastoralists in the project-planning process. Those who depend upon agriculture for their livelihoods should be empowered to ensure that development efforts target what is most relevant to local communities and contexts to accomplish agreed goals in the most effective way.
- Improve access to knowledge and germplasm. This has been shown to significantly improve farmers' willingness to plant or cultivate more trees for multiple purposes. Farmer to farmer dissemination and educational visits provide potential alternative mechanisms and increase adoption rates.
- Improve land and tree tenure. This can have a significant effect on farmers' willingness to invest in their land and improve productivity. Reducing state regulation of farmer management, harvesting and selling of trees on their own farms is an important reform needed in many countries.
- Overcome the barriers of high opportunity costs to land. This is a key requirement for successful implementation of climate-smart agriculture in developing countries and to-date it has been given little attention. Many improved management practices provide benefits to farmers only after considerable periods of time. This can be prohibitive for poor households because investing in new practices requires labour and incurs costs that must be borne before the benefits can be reaped. Payments for carbon sequestration may be an appropriate way of covering the time lag between investing in climate-smart practices and obtaining the environmental and economic benefits.

- Improve access to farm implements and capital. Credits, loans and other forms of access to capital can significantly reduce farmer vulnerability, particularly in combination with insurance schemes that protect against income losses arising from weather extremes.

During last more than three decades many agroforestry technologies have been developed and demonstrated by the research organizations. But most of them have not reached to farmer's field for want of awareness, inadequate infrastructure and lack of policy support. Therefore, the desired impact has not been observed in terms of adoption of technology. However, policy issues related to agroforestry as such has not been taken up for research studies. But discussion in various meetings, seminar, workshops and symposia these issues have always found place (Dhyani and Handa, 2013). It is known that the growth and development of agroforestry is influenced by various policies of the economy like credit, trade, taxation, power, transport, etc. These policies impact the sector either directly or indirectly besides the core forest and agricultural policies which have a larger bearing on the agroforestry programme in the country. State regulations and permit systems for felling of trees and for timber transportation have been main interferences in marketing of timber grown on farmers' land by private investment and have been major discouragement to the expansion of agroforestry, besides, marketing of agroforestry produce is not organized. Thus, a consensus emerged recently that India needs urgently a policy on agroforestry. The initiative for a National Policy on Agroforestry in India were taken at the same time when FAO was preparing guidelines for decision makers for advancing agroforestry on the policy agenda (FAO, 2013). After long deliberations and discussion India launched a forward looking National Agroforestry Policy in 2014. However, to implement the same appropriate guidelines for production of quality planting material and supply system and coordination, convergence and synergy between various sectors linked with agroforestry will be required. This will require adequate research interventions and support as well as trained manpower.

Conclusion

The agroforestry technologies developed based on R & D work in India has a considerable potential to meet the challenges in the current scenario of climate change. A number of technologies for different agro ecological zones of the country have been identified and suitable tree and crop combinations have been identified. The technologies provide option for livelihood, environmental and energy security. There is further need to upscale these technologies to achieve the desired targets.

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Annexure - I

Promising agroforestry systems for different agroclimatic zones of the country.

Agro-climatic Zone	Agroforestry system	States	Tree Component	Crop grass	/ Net Income / year
Western Himalayas	Silvipasture (RF)	Himachal Pradesh	Grewia optiva	<i>Setaria spp.</i>	18670
		Uttar Pradesh	<i>Morus alba</i>	<i>Setaria spp.</i>	19732
	Agrihorticulture	Uttarakhand	<i>Prunus persica</i>	Maize, Soybean	4360
Eastern Himalayas	Agrisilviculture	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, West Bengal, Sikkim	<i>Anthocephalus cadamba</i>	Paddy	13880
Lower Plains	Gangetic Agrisilviculture	West Bengal	Eucalyptus	Paddy	10603
Middle plains	Gangetic Agrisilviculture	Bihar	<i>Populus deltoides</i>	Sugarcane- Wheat	24281
	Agrisilviculture	Uttar Pradesh	Eucalyptus	Rice-Wheat	16124
	Agrisilviculture		<i>Dalbergia sissoo</i>	Sesamum	11600
TransGangetic plains	Agrihorticulture	Uttar Pradesh	<i>Emblica officinalis</i>	Black gram/ Green gram	13108
Upper plains	Gangetic Agrisilviculture	Haryana	<i>Populus deltoides</i>	Wheat, Bajra fodder	37125
Eastern Plateau & Hills	Agrisilviculture	Punjab	<i>Gmelina arborea</i>	Paddy, linseed	26402
Central & Hills	Silviculture	Delhi, Bihar, Jharkhand, Madhya Pradesh, Orissa, West Bengal	Bamboos		6700
	Plateau Agrihorticulture (Irrigated)	Madhya Pradesh, Rajasthan, Uttar Pradesh, Maharashtra	<i>Psidium guajava</i>	Bengal Gram	11700
	Agrihorticulture (RF)		<i>Emblica officinalis</i>	Black gram/ Green gram	13108
	Silvipasture (RF- Degraded lands)		<i>Albizia amara</i> , <i>L.leucocephala</i> , <i>D.cinerea</i>	C.fulvus, S.hamata, S.scabra	6095
	TBOs (RF)		<i>Jatropha curcas</i>	-	3741
	& Agrihortisilviculture (Irrigated)	Karnataka, Madhya Pradesh	<i>Tectona grandis</i>	Paddy, Maize	80613
	Plateau Agrisilviculture (RF)	Andhra Pradesh, Karnataka, Tamil Nadu	<i>Achras sapota</i> , Eucalyptus	Cotton	25605

Agro-climatic Zone	Agroforestry system	States	Tree Component	Crop grass	/ Net Income / year
	Agrisilviculture (Irrigated)		Eucalyptus	Chillies	38695
	Block Plantation (RF)		<i>Leucaena leucocephala</i>	-	12810
	Block Plantation (RF)		Eucalyptus	-	32666
	Agrihorticulture		<i>Tamarindus indica</i>	Chilli	16126
	TBOs		<i>Pongamia pinnata</i>	-	4000
East Coast Plains & Hills	Agrisilviculture (RF)	Andhra Pradesh Tamil Nadu Pondicherry	<i>Ailanthus excelsa</i>	Cow pea	13237
West Coast Plains & Hills	Agrisilviculture (RF)	Kerala Maharashtra Tamil Nadu Goa, Karnataka	<i>Acacia auriculiformis</i>	Black Pepper	114240
	Agrihorticulture (RF)		<i>Artocarpus heterophyllus</i>	Black Pepper	97440
	Agrisilviculture (RF)		<i>Acacia auriculiformis</i>	Paddy	21032
	Agrisilviculture		<i>Casurina equisetifolia</i>	Paddy	24968
Gujarat Plains & Hills	Coast Agrisilviculture	Gujarat Dadra & N. Haveli Daman	<i>Azadirachta indica</i>	Cow pea	10896
Western Region	Dry Agrisilviculture	Rajasthan	<i>Ailanthus excelsa</i>	Green gram	6025
			<i>Prosopis cineraria</i>	Pearl millet	30215
	TBOs (RF)	Lakshadweep	<i>Jatropha curcas</i>	-	3741
All Islands	Agrihorticulture		<i>Cocos nucifera</i>	Paddy	15433

Chapter 6

Technological advancement in agro-forestry systems: Strategy for climate smart agriculture technologies in Maldives

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Abstract

Farming systems in Maldives have been derived from ‘Agroforestry’ systems. It is true that all the farmers in the country value their tree as much as they value their crop. They had valued the crop for the food, income, and shade and relaxing environment for the people and shelter for the crops, soil fertility, protection against strong winds etc. During the 24 December Indian Ocean tsunami, waves of 1-4 meters smashed to the islands of the Maldives agriculture systems such as backyard gardening with perennials such as coconut, breadfruit, mango, citrus, pomegranate, guava and Semi –perennials and annuals like banana, papaya, chili, root crops, and vegetables. In addition the Horticultural crops such as papaya, pumpkin, eggplant, sweet potato, cassava, watermelon and other cucurbits are grown in field plots got destroyed. The impact of the wave caused destruction to homes, standing crops, loss of farming equipment damage to agriculture infrastructure decline in yield levels of field and other crops including coconut and fruit tree. Irrigation affected the ground water. The Direct losses estimated to be MVR 137.63 Million (\$US 10.75). About 317.1 ha (50% of the field plots) in the inhabited islands got destroyed due to saline water intrusion and loss due to crop failure and loss of 269,330 plants. Apart from the fields, perennial trees such as coconuts, breadfruits, mango, betel leaf, guava, water apple are reported to be uprooted by the waves and dying (except coconut) because of salt toxicity.

This is the turning point of agriculture. Major changes were taken by the government to encourage farmers to plant trees after this event. Many programs were conducted in distributing plants such as mango, breadfruit, coconut tree, guava etc. Therefore, it is important to gather knowledge, both local and technical information regarding Agroforestry systems and the use of trees in agriculture. This important knowledge is not available as information at the ministry level. It is important for a fragile island ecosystem like Maldives to consider developing extension materials to help farmers adapt to better utilization of natural resources.

The rationale of writing this country status report on “technological advancement in agro- forestry systems: strategy for climate smart agriculture technologies in SAARC countries” is to document the innovative Agroforestry practices under the influence of climate change and to assess the productive and environmental functions of trees in agriculture landscapes and its contribution to food security and to identify the emerging issues and to propose strategies to develop Agroforestry in the country.

As a country who is threatened by the sea-level rise and faces direct consequences of climate change it is important as a country to motivate farmers to take up tree farming for improving their own livelihood in view of the fruits and other usufructs, make the islands self sufficient to meet domestic demands of timber, small wood and fuel wood to ensure long term ecological security and for the enhancement of recreation value areas.

Introduction

The Republic of Maldives is an archipelago of 1192 small coral islands that stretches over 90,000 square kilometres in the Indian Ocean making the country one of the world’s most dispersed countries. Amongst these islands there are 187 inhabited islands with a total population of 341,256 (as of census 2014). These naturally formed islands are divided into 20 atolls for administrative purposes. The capital city Male’ located in Kaafu Atoll has a size of 1 square km. Less than 1% of the nation’s total economic zone consists of land. Among all these islands, only 28 have a land area greater than one square kilometre. 27.2% of the inhabited islands have a population of less than 500 and 62.5% of the inhabited islands have a population of less than 1,000. The capital city Malé has a population closer to 133,019 people or almost 39% of the population.

Apart from Male’, islands can be sorted into the following categories: resort, primarily fishing, mixed fishing and agriculture, and predominantly agriculture practicing islands. Majority of the islands depend on fishing and mixed farming. Very few islands have land area bigger than one square kilometre with an average height of 1.5 meter from sea level.

Commonly found trees and shrub species in Maldivian environment are tolerant as the islands are small and low lying. These species are documented in “Trees and Shrubs of Maldives”, V. Selvam 2007. Salt intrusion into the islands is common in islands during North East monsoon and poorly adapted species are often suffered badly or die in these incidents. Many poorly adapted species are endangered due to the salt intrusion caused by Tsunami 2004.

Forests in Maldives are generally designated for soil and water conservation, landscaping and natural beauty of islands and coastal protection. Forests are among the few resources that the people of Maldives have a great dependence on

to accomplish basic needs. Coconut being the highest percentage of forest cover avail the island communities with the extensive use of coconut palms; coconut and oil as a major food source, palm trunks as timber to build transportation vessels, build up shelter, household utensils, furniture, thatch from palm leaves as roofing material.

Furthermore, forest plays a major role in providing wildlife habitats, protects land and water resources and therefore vital for development of the tourism sector. Forests also represent crucial, self-maintaining repositories of genetic resources.

Changes in economic, social and demographic settings generate demand for land. Forest lands are mostly cleared for the expansion of agriculture, industrial growth, and development of tourist resorts and to provide housing to cater to the demands of the growing population.

Agriculture and climate change

Climate change is defined by Intergovernmental Panel on Climate Change (IPCC) as “the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity” (IPCC, 2015). Maldives has a tropical monsoon climate. The south-west monsoon is from May to November and the north-east monsoon is from January to March. Daily temperature varies between 31°C to 23°C. The mean daily maximum temperature is 30.4°C and the mean daily minimum temperature is 25.7°C. Humidity ranges from 73% to 85%. The annual average rainfall for Maldives is 2,124mm. Southern atolls on average receive 2,277mm while northern atolls receive 1,786mm of rainfall annually.

The Change in climate is hitting hard on the agriculture sector in the Maldives; it brings dry spells, floods, strong winds, new pests and diseases. As a result of this there has been a negative impact on the agriculture industry due to poor crops, less food and lower incomes. Change in the Climate also accelerates land degradation and have negative impact on livelihood activities. Climate change has become a reality, it is time that we find ways to grow crops and manage lands with higher yields, based on climate resilient systems while storing carbon in plants and the soil at the same time. It's the technique of using climate smart agriculture by implementing better water harvesting methods to capture run off for better quality crop production and helping farmers to adapt to erratic rainfall during the wet season, and by encouraging farmers to use shelter belt trees to protect the farm from strong wind and creating awareness among farmers on how these trees provide nutrients through their roots and leaves and how they are a

source of fodder for livestock and fire wood for kitchen. Mulching and intercropping are practices that ensure more reliable yields.

Some of the impact that we have on agriculture sector of the Maldives due to climate change includes the negative impact on crop productivity. The quantity and quality of the crops is affected due to prolonged dry spell and high intensity rainfall. Due to higher temperature although there is an increase in the intake of CO₂ by the crop, the water loss due to evaporation and soil nutrients prevents crops from absorbing the nutrients hence decreasing the yield. Similarly, an increase in rainfall results in inundation of crops resulting huge loss of crops due to flooding. As the main source of water used for irrigation purpose is the ground water and harvested rain water/rain fed systems. When the temperatures increases (situation further worsen by lower rainfalls) will result in loss of water from the soil due to evaporation and this will force farmers to irrigate plants more frequently and in more quantity as most of the crops grown in the country belongs to cucurbitaceous family. Due to this excessive pumping of ground water for both household and irrigation, the fresh water lens is drained and salinization occurs.

Therefore this negative impact has an effect on the growth of the plants due to higher temperatures and higher humidity by creating an environment that is favorable for pest and disease to thrive.

Although the livestock (mostly goats) and poultry (mostly chicken) industry in the country is at its development stage the increase in the temperature during the dry season and high rainfall during the wet season would favor the development of pathogens and results in an outbreak of diseases and threatens the livelihood activities of the people. During the dry season some of the islands report shortage of drinking water, so if this is the case, lack of portable water for livestock/poultry also needs to be considered.

The impact on Forestry due to severe climate conditions include some pests are more attracted and have a higher reproductive rate when plants are stressed. Thus decrease in the available water in soil due to evaporation would stress the plants for water. This will make the plant more attractive to the pest and increase their population leading to more pest outbreaks. This has been observed with *Euproctis fraterna* locally known as huvani outbreaks in many islands during the warmer period of the year.

Although no link can be established between high tide and high temperature, the beach erosion in Littoral forest areas locally known as heylhi is more prominent and soils are being washed away to sea due to storms and swells.



Figure 1 Beach Erosion N.Orivaru Island



Figure 2 Pest Infestation - White flies on Guava tree



Figure 3 Wind damage in Kaashidhoo Island 2010

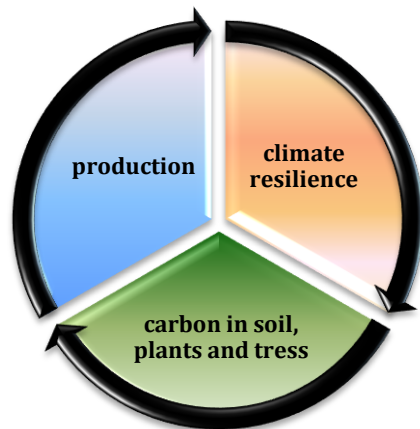


Figure 4 Wind damage in Kaashidhoo Island 2010

Studies shows that agriculture, soil erosion, and deforestation together contribute a third of greenhouse gas emissions, while climate smart agriculture brings yet

another benefit because healthy farmlands capture carbon in vegetation and in the soil as well, if farmers increase carbon in the soil by using climate smart agriculture as shown in the below figure, we could reduce the greenhouse gases in the atmosphere. Diagram 1 (below): climate smart agriculture.

Therefore we need to understand that climate smart agriculture is a triple win, there is more food on the table, there are healthier landscapes more resilient to dry spells and floods and at the same time plants and soil capture more carbon hence climate smart agriculture it is a path to green growth (World Bank).



Agroforestry systems in the country and their classification

People have been practicing trees in farms for generations. Such practices improve the livelihood through supply of fruits, firewood, fodder and organic fertilizer for the home gardens. Agroforestry systems mitigate climate change, enhance on-farm biodiversity. A dynamic, ecologically based, natural resource management system that through integration of trees on farms and in the agricultural landscape diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels is referred to as agro-forestry (ICRAF, FAO).

As the dominant tree species in Maldives forestry is *Cocos nucifera*, locally known as “Dhivehi ruh”, ways in how coconut based Agroforestry system has been adapted in the islands will be discussed in this paper. Although coconut palm is a horticultural species and can't be considered as a forest species, a substantive part of the tree vegetation in the islands is pure natural stands of coconut palms. Therefore, the coconut thickets play a very important role in the economy of the island. Most of these stands are immediately behind the littoral forests, on the landward side of the island and act as an effective coastal shelterbelt. Some of the major systems of Coconut based Agroforestry currently practiced in the Maldives are discussed below.

1. **Coconut based annual crop Agroforestry systems** – where intercropping with annuals such as cassava and vegetables, this form of practice is common among coconut growers due to short payback period and easy management practices.



Figure 5 Coconut based Agro Forestry system inter cropped with Cucurbita moschata in AA.Thoddoo Island

2. **Coconut based perennial crop Agroforestry systems** – farming system in which perennial or semi-perennial trees are grown together in mature coconut stand of 20-25 years and above. This type of practice is popular among smallholders due to scarce land resource. Fruit trees such as Pond apple, Custard apple, breadfruit, and mango are commonly used perennial crops in coconut plantations where the growth period exceeds 10 years. Banana, passion fruit, papaya, betel are intercropped as semi-perennial with the growth period of 2-5 years.



Figure 5. Coconut stand with Banana plants in S.Meedhoo Island



Figure 6 Coconut Plantation with *Punica granatum* in HDh.Hanimaadhoo Island

3. **Coconut based coastal Agroforestry system** –coconut based coastal Agroforestry systems will supplement ecosystem services provided by mangrove and coastal vegetation systems and make an important interplay with highly urbanized systems. It helps to prevent from soil erosion and improve soil fertility. the few number of casualties in islands during the 2004 Tsunami was due to this natural coastal belt that reduced the power of the wave that washed onto the shores.



Figure 7 Coconut stand with *Hibiscus tilaceus* (Dhiggaa) and *Thespesia populnea* (Hirudhu) in HA.Filladhoo Island

4. **Coconut home garden Agroforestry** – This system compromise of a variety of tree crops with multiple uses (perennial food crops, fruits, vegetables, roots, tubers, medicinal plants). This system will provide high level of nutritional and diet diversity to household's fruit trees provides additional income.



Figure 8 Home Garden in GN.Fuahmulah Island. *Cocos nucifera* with *Mangifera indica* (Mango) and Banana plants



Figure 9 Home Garden in GN.Fuahmulah Island - *Cocos nucifera* with Taro and Banana plants

Association and interactions

Purpose of applying coconut based Agroforestry systems

Compared to coconut monoculture, which is rarely practiced in Maldives, the land under Agroforestry are more favorable and stable for sustainable agricultural production. Some of the benefits derived from the system are described below.

1. The system helps to diversify and integrate the components within the system, and support sustainability

Inclusion of other trees, crops and livestock into the coconut monoculture system and their co-existence with coconut helps to increase species diversity within the farming unit. When these components are integrated into the system, all the components will act as complement each other with positive and synergistic interactions than competition with negative interaction, thus increasing the efficiency of production system. This diversity will enable farmers more security in terms of food and income. In addition to better coconut harvests, other crops can also be harvested hence increasing household income.

2. Increase productivity in farm unit.

Increase overall productivity from the unit holdings without adversely affecting the coconut production. Mixed cropping experiments has not been done at ministry level, however this method has been practiced by the farmers for many years. Satisfactory performance of annuals under coconuts, root and tuber crops such as cassava, sweet potato, taro, yam, vegetables and leafy vegetables such as Brinjal, beans intercropped with coconut is practiced by some farmers



Figure 10 Farm intercropped with *Carica papaya* (Falho) and leafy vegetables

3. Improvement of soil fertility

The soil composition of Maldives is young and comprise of sand and a thin layer of dark soil containing organic matter. These soil have very high infiltration rates and hence low water- holding capacity, due to excess calcium soil pH varies from 8.0 - 8.8. (Prakash, 2008). The soils are deficient in nitrogen and potassium due to excessive leaching. This problem is further aggravated by low organic matter input added into the soil from coconut monoculture and the decline in mineralization of organic nutrients. Agroforestry system will improve the soil physical, chemical and biological properties. This can be explained by the litter production and decomposition that helps to maintain higher soil organic matter and water relations in such systems. The nutrient cycle becomes more effective as tree components deep root systems absorb and recycle nutrients from subsoil that would have been otherwise loss by leaching.

Dense canopy cover provided by the trees/crops protects soil against the direct action of heavy rain, thus reducing surface runoff. Organic matter and plant nutrients on the ground due to leaf litter and decomposition of it. The improvement of soil physical (bulk density, soil moisture, water holding capacity) and chemical (organic matter content, total nitrogen, available phosphorus, exchangeable potassium), and biological properties (earth worms population). Incorporating Gliricidia foliage into the soil as a green manure improve the fertility of soil. Higher water availability in intercropping by reduced surface runoff.

4. High and earlier economic benefits at farm level

Net income from a unit holding under Agroforestry system provides high consistent income than mono-cropping. It ensures s reasonable cash flow during the pre-bearing period. Reduction if the use of fertilizer, weeding and inter-cultivation costs can be identified as economic benefits. Agroforestry can also substantially raise the monitory value of the coconut lands. Benefit cost ration is higher and this model is more profitable than others.

5. Create favorable microclimate and environmental services

Favorable microclimate for the coconut and various level of shade loving understory crops by increased utilization of sunlight, reduced so temperature, and also increased soil moisture over coconut monoculture system. Agroforestry systems can play an important role in the adaptation to climate change by changing the micro-climate, protecting the environment by provision of permanent cover, improving efficiency of the use of soil, water and climatic resources, reducing carbon emission. It also provides opportunities for crop diversification and soil fertility improvement. It is important to implement management systems of coconut based Agroforestry systems in agricultural landscapes to provide products/services that can relieve pressure on the forest

resources. The functions of the coconut based ecosystem are detailed in Annex 1: source (D.K.N.G Pushpakumara, 2011).

Agroforestry technologies

In the paper we will be focusing three areas:

1. Trees for forage
2. Use of crops in Agroforestry system
3. Windbreaks

1. Trees for forage

There are basically two ways of managing trees for forage. The first way is the animals graze the trees in the paddock or forage is cut and carried to the goats. The main forage legumes used are *Leucaena leucocephala* (locally known as ipil ipil) and Gliricidia. Other potential tree legume species include *Sesbania grandiflora* (locally known as feerumura'ga) *Albizia saman* (locally known as bodu gas), *Pterocarpus indicus* (locally known as Ofi eley gas), and *Moringa oleifera* (locally known as muran'ga gas). *Hibiscus tileaceus* (locally known as dhiggaa) is also a suitable dry season fodder. These trees have a deep rooting nature therefore it is beneficial in the dry season for maintaining protein, energy and mineral supplies in grazing goats.



Figure 11 *Moringa oleifera* (Muran'ga gas)



Figure 12 *Hibiscus tilaceus* (Dhiggaa)



Figure 12 *Albizia saman* (Feerumura'ga)



Figure 13 *Gliricidia sepium*

For the legume species to be acceptable to farmers the tree should possess the following characteristics:

- Ability to fix nitrogen
- Well adapted to poor and difficult soil conditions
- Ability to compete with other vegetation
- Multiple uses e.g. poles, firewood, fruit
- Should be able to act as a complementary tree, hence allow adequate light for the understory grasses with non-limiting competition from tree roots for water and nutrients
- Able to produce under repeated grazing
- High nutritive value and acceptability to goats
- Easily propagated from readily available seeds, cuttings or seedlings
- Limited in seeding under potential non-grazing situations

2. Use of Crops in Agroforestry systems

In an Agroforestry system, crops form the lower level of the canopy while trees form upper level of the canopy. It is important to know the characteristics of the combinations of trees and crop species in order to improve the productivity of Agroforestry system.

Usually crops form the lower level of the canopy therefore it is assumed to have tolerance to some degree of shade. Hence, crops that have high tolerance level to shade will have better yield in an Agroforestry system. The amount of shade provided by the tree will depend on the species and varieties, spacing arrangement and the age of the plants. In an Agroforestry system most of the time the crops have to compete with trees for moisture and nutrients. Therefore, the success of the crop will depend on the aggressiveness of the crop. The distribution of the root system will play an important role in determining the degree of competition. However, looking at the positive side trees provides shelter for the crop and reduces potential damages caused due to high wind.

Potential food crops that can be integrated into Agroforestry systems in the Maldives

Food crop	significance	Crop requirement	AF potential
Taro (locally known as ala)	staple food in most of the southern island	Adopted to high moisture conditions, do not tolerate drought, very shallow roots like 15-20cm, high demand for nutrients like N,K, mostly grown in wetlands 'chas bin' , no fertilizers are used , often grown as a monocrop, but grown with other root crops, banana. Shading may improve establishment and early growth, but later in growth it has detrimental effect on the corm development and yield	Have some tolerance to shade at the early stages (usually 3 months after planting), at the later stage do not tolerate to heavy shade, the crop is very susceptible to moisture and nutrient stress, cultivars with larger root systems may be better suitable for AF
Yam (locally known as ka'tala)	Cash crop for most of the southern farmers,	Grow best with rainfall of at least 1500mm/year, it requires 6 month of growing season, with sufficient rainfall. Proper drainage is essential and do not tolerate water logging. Do not tolerate severe competition for nutrients, staked for improve yield, fair tolerance to shade in early growth, but need needs sunshine for good yield.	Need for vines for support makes yam an ideal crop to combine with trees. Yams can be staked on live plants or cut branches of trees as to support the vines, and it is important to ensure that the yam canopy is fully exposed to sunlight at later stage of growth.
Cassava (locally known as dhandi aluvi)	Staple food for some islands, high cash crop	Grows best in rainfall of about 1500-2500mm / year. Under high rainfall conditions excess amount of vines are produced and little tuberous root. Well tolerant to drought , does not tolerate shading	Very sensitive to shading ; thus shading needs to be taken into account

Windbreaks

For the last couple of years, extensive damages have been caused to crops at different parts of the country due to strong winds. Salt spray from the ocean breeze had caused burning of the crops. When land is cleared for any agriculture purpose it is important to keep in mind to protect the farm land from natural wind breaks. Windbreaks are Single or multi lines of trees which shelter an area from prevailing winds (programme, 1999). They can be formed by leaving areas of natural tree and shrubs growth when clearing land, or by planting rows of trees with the aim of reducing wind speed.

Wind can be a very destructive especially when combined with high temperature, salty sea breeze. Windbreaks will help to conserve plant and soil moisture, prevent damages to crops; soil lost through wind erosion and surface runoff due to heavy rainfall, and reduces sea salt spray.

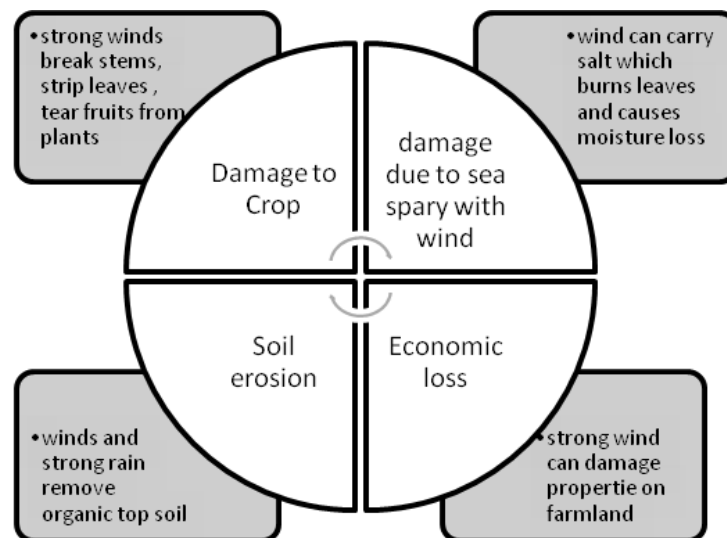


Figure 14 (above): wind related problems

Windbreak designs

Where no natural protection exist, planting windbreaks to improve the environment for agriculture. A well designed windbreak with say trees with 10m tall, crops unto 100m away will gain come sort of protection from strong winds.

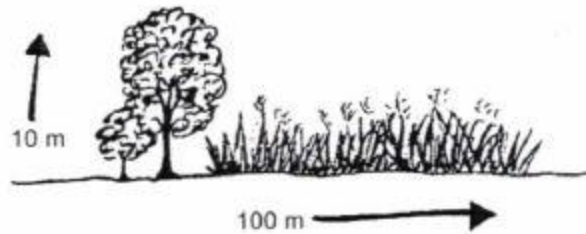


Figure 15 Wind breaks with 10m tall trees

Windbreaks should be planted in the windward side of the agriculture land hence more effective when they are oriented 90° to prevailing wind direction. Under Maldivian condition, when agriculture land is small, it is better to plant single row of trees or multiple on the boundary or a live fence. Plant trees closely enough within rows so that mature tree crowns will overlap. The best spacing for medium sized trees is 3m to 4m. Plant smaller trees at 2 to 3m apart and larger trees at no more than 6 m apart.

Special consideration should be taken not to shade-out smaller row by the larger row. Trees should be planted in parallel rows, make sure not to make the shelter belt too dense because it might cause turbulent air movement downwards. When choosing a species to be planted, choose a plant that will be able to take strong wind, deep rooting and well adapted to the site. Species with low branching and narrow crowns like *Casuarina* can be used as the foliage filters the wind rather than blocking the wind. Windbreaks can also be able to provide fodder, fuel wood, poles, fruits and mulch.

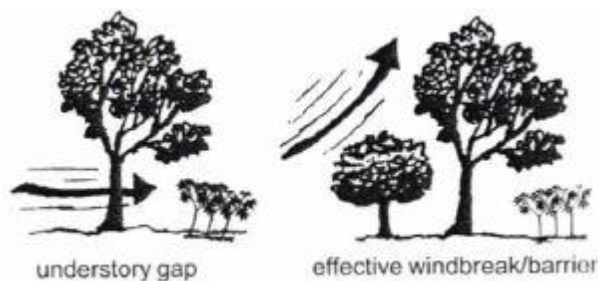


Figure 16 Effective windbreak

Agro forestry potential as CSA technology

Dealing with agriculture, weather smart, water smart, carbon smart, energy smart, and knowledge smart. This should benefit both farmers and society. It is an everyday challenge for us to meet the climate risk in a ways in which it is

environmentally safe environmentally sustainable. Better Research programs should be conducted at Agriculture research center located at Hdh.Hanimaadhoo in order to address climate change, agriculture and food security issue. Work needs to be undertaken to develop “climate Smart Islands”. These will be sites with diverse rate of stakeholders converged to strategies about the best interventions that will fit to the local context. The idea is that climate smart technologies and climate information services to be integrated into island development plans. Using local knowledge supported by local institutions.

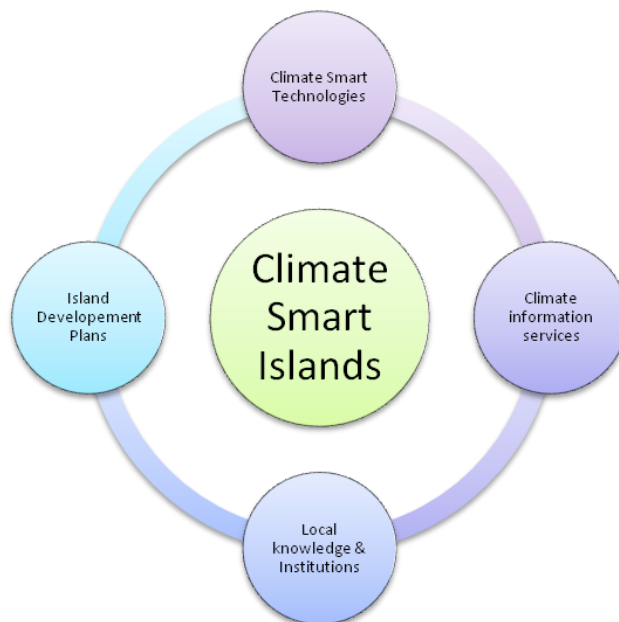


Figure 17 Climate Smart Island Concept

The key focus in climate smart islands is to enhance climate live to see among farmers and other stakeholders introduced technological and institutional interventions agriculture that will enhance the production, income and climate resilience and adaptations, at present this model has not been implemented in the Maldives. The site selection has to be made in areas that are more susceptible to changes in climate change, such as heavy rain, pest and diseases and flooding.

Climate smart Islands models will start by creation of corporative societies that consists of farmers, researcher and island council officials. They begin by prioritizing climate smart technologies that can be adopted by the farmers; feasibility studies needs to be undertaken, such studies should be participatory and inclusive. Capacity building programs on gender and climate change for farmers and climate smart islands. Farmers in climate smart islands implements a range of technological and institutional interventions such as value added service (weather forecast), floods insurance scheme (allied insurance scheme), efficient irrigation

management systems , adaptive cultivars , conservation management based agriculture practices, and range of other low greenhouse gas emitting options. Adopting strategies that maximize synergies between adaptation, mitigation, food production and sustainable development.



Figure 18 Climate Smart Adaptation Strategies

Climate smart islands will be an example by increasing food production while remaining environmentally sustainable. Such models will be demonstrated in north, central and south around 60 farmers of Maldives. Farmers can now make the right decisions to counter climate induced problems and contribute to global food security and a cleaner environment. (CGIAR Research Program on Climate Change, 2014)

Constraints to up scaling Agroforestry

Several constraints can be identified in up scaling Agroforestry system in the Maldives, Monoculture has been encouraged and practiced in the country, and the crop diversification is comparatively low. Some of the constraints we identified summarized in the below diagram.



Figure 19 constraints of the coconut based Agroforestry in Maldives

Physical constraints– since coconut is a rain fed crop, longer dry periods due to adverse weather will impact heavily on coconut production when intercropped, and due to poor soil conditions and limited ground water availability it will be hard to adopt such kind of system

Institutional constraints- lack of department involved in Agroforestry research in coconut lands and poor research and extension linkages, lack of knowledge and capacity can be identified, the price fluctuations of coconut (see annex 11 . coconut and tender coconut price variance for the period 2011-2014). These variance indicates that due to poor data collection the trend cannot be identified. Other factors include lack of marketing skills for such intercropped products.

Technical constraints- Agroforestry system requires additional resources to fully function such as labor, capital etc., in order to identify this cost-benefit ratio analysis needs to be done and know the revenue generated by the farmer by adopting an Agroforestry and monoculture system. Most of these systems require management of crops, trees and its inputs and skilled knowledge compared to monoculture. For multi strata, the competitive negative interaction both from above and below ground resources such as tree canopy shade the palm or when the root systems overlap. If this is the case proper management practices such as pruning and thinning of associated trees is essential to limit competition. Farmers are not trained for such an intensive management practice.

Socio economic constraints-land ownership issues related to practicing such a system; there is no law governing ownership of agriculture land. In addition, Theft of harvestable products, shortage of hired and family labours and ban of expatriate to work on agricultural land. Increasing cost of the land further worsens the situation.

Pest and disease: Agroforestry systems may also increase pests when the trees in the system are increased and this will expand the availability of food to insects by serving as alternative hosts. Physiological status of the species may make them vulnerable to or strong against insect attack. Pests can damage crops in the Agroforestry system and affect the sustainability of the system. Pest problem is likely to occur from introduction of pests through importation of plant material, or due to some unusual feature of the system. One such incident is the introduction of oriental fruit fly recorded on 20th April 2015 in Sh.Feervah that can cause extensive damages to the fruit trees such as mango. Some of the pest management practices that can be adopted in a CBAS are shown in below.

Table 1 (above): Pest management in coconut based Agroforestry systems

Action	Strategy
Composition of the components	-Identify the condition for the survival of natural enemies of the pest (biological control measures) -Creating favorable condition for the natural enemies of the pest -Plants with undesirable characters (eg toxic to natural enemies) should be avoided
Taxonomic relations of plants	-Coconut based Agroforestry systems with closely related plants such as ornamental palm species and betel nut pal can attract more pests such as coconut scale, beetles etc... -Plants that are taxonomically far apart with narrow pest complex and have resistant would be suitable for pest management
Host range of the pest	-Plants that have narrow host range are more suitable for Agroforestry systems -Introduced plants can become host plants to native pests or with time the pest have higher reproductive rate in new host plants
Introduction of exotic plants and pests	-Phytosanitary and quarantine measures should be in place in order to avoid unnecessary plants that would otherwise be considered invasive -Accidental introduction of exotic pest into the system without a biological control agent. any natural enemy should be introduced with caution into the system
Micro-climate	-Change in micro-climate due to shade will directly and indirectly effect activities of the pests and their enemies by reducing temperature, increasing humidity and protection from direct sunlight
Management practice	-Chemical control methods to bring pests population as fast as possible , toxicity chemicals on non-target insects will aggravate the pest problem by disturbing the balance between the pests and their natural enemies
Competition for resources	-pests can remove certain amount of vegetation, mulch and organic matter in the system, therefore components and management practices is important to avoid competition among the components

Potentials for improvement

As coconut is the dominant forest tree in Maldives, ways in better utilizing the existing natural stands is vital. Every year, the productivity of the coconut stands is getting low. Different pests like rhinoceros beetle, hispid beetle is being wide spread and extensive damages are being caused. Therefore, to sustain the products such as coconut, tender coconut, toddy, coconut sugar, palm sugar and other value added products such as copra, vinegar, and thatch is important for the economy

that is dependent on such products for income generation. It is important to improve the coconut industry in the country.

It is important to create awareness amongst farmers to increase productivity of the coconut stands. Such initiatives have already taken by the government by the commitment made to celebrate this year's agriculture day targeting coconut palm. In this paper we will be highlighting ways in which the coconut harvested by an Agroforestry can be used as a sustainable climate smart agriculture technology.

Coconut based silvo pastoral Agroforestry system – it is a farming system in which livestock currently goats Forge cultivation and livestock- under coconuts can help coconut farmers to increase the farm income and food and nutrient supply. This practice of raising goats increase income of the growers and to improve soil fertility through the recycling of livestock wastes. Raising goats on natural/improved pastures integrated with nitrogen fixing trees in potential islands. Tree crops such as Gliricidia (tree fodder), Leucaena leucocephala (ipil ipil) can be used.

There is large potential for developing poultry farming in Maldives. “Free range poultry farming in coconut lands”. This system can be considered as an environmentally friendly organic farming, this system would reduce poverty among rural community. In such a system Gliricidia serve as a multi-purpose and fertilizer tree component in coconut stand. Gliricidia is known as green manure tree and is a cost- effective method of fertilizing in coconut plantation.

Tethering system

This system can be applied in Maldives, especially under coconut plantation with jungles. Goats are generally kept in small or medium size (up to 10 animals). 40-50% of daily fodder requirement of goat can be met through tethering and the rest of the feed can be supplied under stall feeding. It is important to keep the goats in the shed during the night time, and supplementary feeding is required, during the rainy season the goats needs to be stall fed, fresh water and mineral lick shall be available at all times.

Goats can be let out in the morning and return in the late afternoon or early evening. They need to be kept in the shed during night time and rainy season. From grazing alone 60-70% of the daily requirement can be met with desirable weight gain. In the case of Maldives, goats that are kept for mutton production is generally kept in semi extensive way with low input management practices. As a result the level of production is below than expected value.

Goats are very sensitive and even fastidious about taste and cleanliness of their food, have a tendency to refuse to eat from what has dropped to the ground. They should be given a mixed diet like tree leaves, leguminous fodder and grasses. Kitchen wastes from grains, fruits and vegetables. They like to feed at the knee

height, so they like to feed above the ground often standing on their hind legs and resting their fore legs up on the ground. Fodder tree plantations under coconut plantations as live fences along the field boundaries or home gardens. The two trees that can be used include *Leucaena leucocephala* and *Gliricidia*. These trees can also be used as fire wood and timber.

Different legumes have different adaptations therefore it is important to carefully select the best- adapted species for a particular site. *Leucaena leucocephala* is a high quality tree legume with highest and long-term cattle growth rates of tropical legumes species.

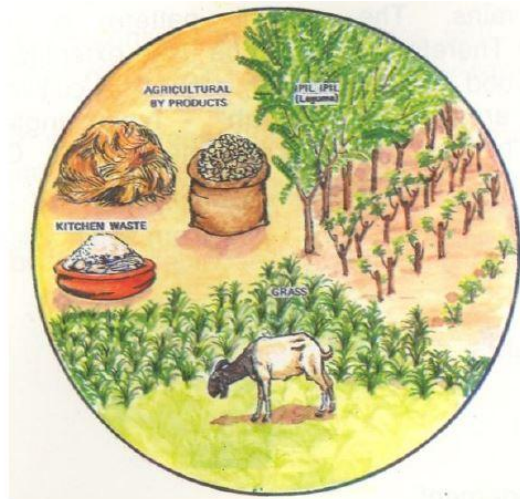


Figure 20 Goats like to mix diet composed of variety of Stuff

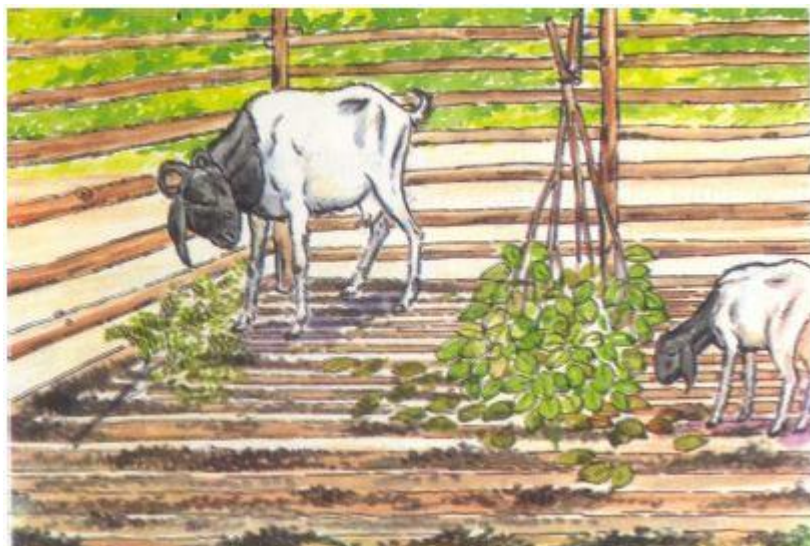


Figure 21 Goats feeding fodder



Figure 22 Goats grazing – At Hdh.Hanimaadhoo Agriculture Centre

Adaptation and species characteristics of *Leucaena leucocephala*:

Leucaena leucocephala is well adapted to soil in pH range 6-8, therefore is best suitable for coralline derived soils of pH 7.5 and greater like in the case of Maldives. The Optimum rainfall range is between 1500-2000mm per year for growth of the tree. In 2014, on an average Maldives experience 2133mm of rainfall. For maximum growth *Leucaena leucocephala* requires high level of calcium and phosphorus.

Management characteristics: Seedling growth is slow initially, at least 9-12 months is required for trees to use as fodder, and hence farmers should consider growing a food crop during this period. *Leucaena leucocephala* is less tolerant of competition than *Gliricidia* (with much higher root density) and regular grazing is necessary to control growth of weeds. Where *Leucaena leucocephala* forms 3-5m thickets cut to 0.5m high Ipil ipil plots of 40 ft. x 35 ft. could supply up to 30% of the daily green fodder requirement of goat herd with 6 breeding females and their offspring's (15-20 goats)

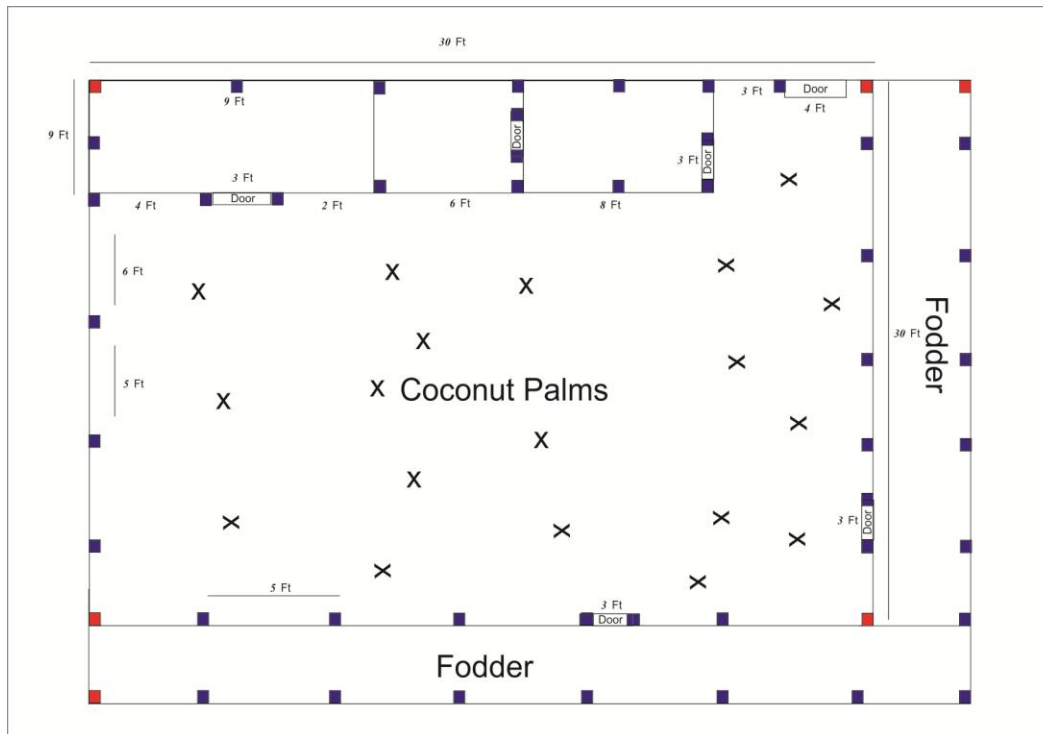


Diagram 6 (above) proposed silvo pasture farm design

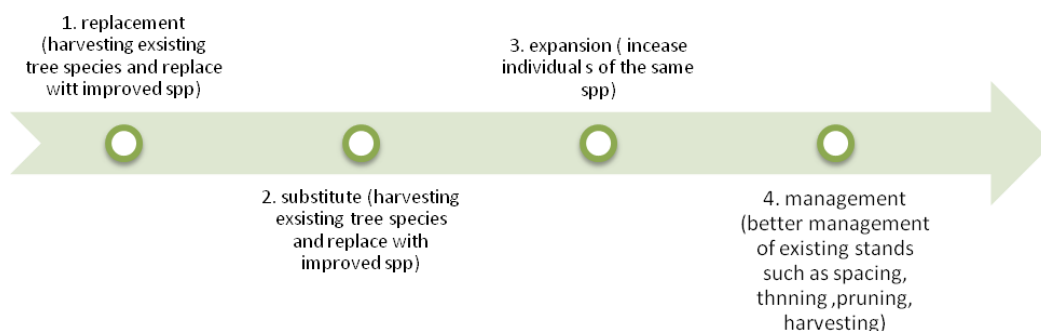
Conclusion

It has been identified that shift from coconut monoculture to coconut based Agroforestry as a national priority for the future development strategy for coconut sector due to higher population, land degradation, low/old productive coconut stands, benefits of integration of Agroforestry approach needs to be considered to address current land use challenges faced. Land degradation, poverty, malnutrition. Depletion of soil fertility and water resources, loss of biodiversity. New land for agriculture is not an option now, yet the demand for coconut is increasing.

The projected changes in intensity and frequency of storms, droughts and floods that could alter hydrological cycles and precipitation, increase of temperature that could impact have major implication on coconut production. Hence, adaptation to climate change would require better preparations. The present challenge would be to identify different Agroforestry systems and establish/implement them. In order to do so, mapping of coconut based Agroforestry and identify sustainability of Agroforestry products is important. This demand for greater interdepartmental collaboration, creating a need for a new collaborative approach rather than distribution of fruit trees/ plant seedlings.

Agroforestry systems increases productivity, building assets, generating income, and better livelihood options. It also contributes to the environment by reducing the pressure on natural habitats, habitat restoration, and ecosystem resilience. In order to do so new models, restructuring and introduction of new technical interventions by a farmer participatory approach can achieve conversion of existing farms into operational models. In this respect farm survey should be undertaken by MoFA and fist hand information needs to be collected regarding the size of the area, present cropping situation, tastes and preference of farmers, innovative practices used by farmers, interventions desired by farmers, feasibility study of implementing suggested interventions, market analysis, economic aspects should be considered.

To enhance the production, productivity, environment, and economic advantages the following four woody interventions needs to be in place.



Coconut growers who store carbon in trees, crops and soils should be rewarded with awards “fehi Fai” on world food day (16th October) / Agriculture day (10th August). Right policy support will be critical in meeting potential of coconut Agroforestry to fully develop in Maldives. Therefore it is necessary to devise and identify an Agroforestry policy. This will enable the government to promote Agroforestry for food, nutrition, ecological, environmental and economic securities of coconut production in Maldives. However, no study has been made on inter-planting to multipurpose trees along with coconut palms. Organic farming is promoted among farmers. Agroforestry system can be developed into tourism spots with the integration of facilities like retail shops for coconut based Agroforestry foods and beverages, handicrafts and labeled and marketed separately, this form of ecotourism is a must to expand the coconut plantation for future economic benefit.

Furthermore, Regional collaboration with countries that already have well-established agroforestry systems can help capacity building of extension staffs and farmers. And share new agroforestry technologies. This can be enabled through formation of a regional network on agroforestry.

Annex 1 functions of the coconut based ecosystem source: (D.K.N.G Pushpakumara, 2011)

Ecosystem functions	Ecosystem services	Ecosystem services in coconut based agroforestry systems
Direct uses		
Production extractable as food	Food production	Fruits, nuts
Production extractable as raw materials	Raw materials for various industries	firewood
Indirect uses		
Regulation of atmospheric chemical composition	CO ² emission regulation	CO2 plant uptake (carbon stock)
Storage and retention of water	Water supply	Improvement of water infiltration rate and moisture retention
Retention of soil	Erosion control, prevent from nutrient losses	Prevention of soil loss by runoff, other clearances, storage of silt and clay by control ground cover
Soil formation process	Soil formation	Accumulation of organic matter
Suppression of weeds	Weed control	Husks for production of crops
Opportunities for ecotourism and recreational activities	Recreation	Agro-tourism like resorts, beach with coastal agro forestry
Aesthetic view of the island	Socio cultural	Aesthetic, educational, scientific values of the eco system

Annex 11 Coconut and tender coconut price variance for the period 2011-2014

Coconut			
	Kg	a.v price	Income/Year (MVR)
2014	326,703.00	6.26	1,102,469.00
2013	112,438.00	7.01	3,158,428.00
2012	112,595.00	5.70	2,245,760.00
2011	106,028.25	6.16	2,215,798.75

Tender Coconut

	Kg	a.v price	Income/Year (MVR)
2014	533,253.00	10.01	2,853,749.00
2013	564,759.00	12.58	2,375,206.00
2012	445,680.00	14.01	2,133,212.50
2011	628,971.00	10.39	2,330,288.00

Annex 111: Particular for plantation (Gliricidia)

Guidelines for using Gliricidia

- Stakes of Gliricidia (live fence) plant straight, branch free section which are 1.5-2 years old, a slant cut at the sprouting end to prevent rotting and bruise the plant end to enable rooting. Plant stakes upright in a hole 40cm deep.
- Planting like this will result in poor root system therefore wind damage is likely. Seedlings can be used as an alternative in such conditions
- Stakes of Gliricidia forms shoots before roots. Leaves can grow well, while the underground stake can rot due to very wet soil, therefore dry season is better to plant the stakes
- Trees needs to be pruned so that branches are above 1.5m and forage branches are lopped and left to lie on the ground.
- Plot spacing: between rows 5-8 ft., within the raw 5-8 ft., spacing for 'live fence' 6-12 plants

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Chapter 7

Technological advancement in Agroforestry systems: strategy for climate smart agriculture technologies in Nepal.

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Abstract

Farming system in Nepal is very complex and is of subsistence type. Forests are the integral component of this system out of many other components. The existing forest resources cannot fulfill the increasing demands of the population in the country. Many forestry programs have been implemented but not succeeded well enough to fulfill these forest based demands of the people. Hence, they are facing the problem of resource constraints. In this context, Agroforestry has been recognized as a promising scientific technique to achieve sustainability in land use and provide for the needs of the local population. It provides a sound ecological basis to increase crop and animal productivity, more economic returns, greater biodiversity and increased social benefits on a sustained basis. Planting trees on agriculture land or the practice of Agroforestry can protect forest by making tree products such as firewood and fodder easily available to farmers, restore fertility of land by decreasing soil erosion, adding nutrients through decomposition of leaf litter and nitrogen fixation, recycling leached-down nutrients and helping breakdown of nutrients in the subsoil by means of deep roots. Problems such as shortage of forest resources have been reduced by the Terai and mid hill farmers through retaining or keeping trees in various parts of their farmland along with crops for centuries despite having limited landholding. These days it is recognized as a greenhouse gas-mitigation strategy. Therefore, this paper intends to find out technological advancement in Agroforestry systems. Various websites were searched for that of literature review. Some reports were also taken as references from different sources.

Introduction

Country background

Nepal is a land-locked country occupying the central part of the southern slopes of the Hindu-Kush Himalayan arc occupying an area of 147,181 square kilometers between India and the Tibetan Autonomous Region of China. On an average, it extends for 885 kilometers in the east west direction and for 193 kilometers in the north-south direction. The altitude ranges from around 60m in the Terai to more than 8000m in the High Himalayas. There are about 200 peaks of over 6,000m and 13 peaks of over 8000 m. More than 80% of the land surface

consists of rugged hills and mountainous terrain and 20% of the country is covered by Gangetic plain. Most areas fall within the sub-tropical monsoon climatic region, but because of its wide range of topography, precipitation varies greatly from one place to another. The average rainfall ranges from 250 mm to 4500 mm. The average annual economic growth at constant prices during the Three Years Plan period (2013/14 – 2015/16) was just 4.0 percent, with 3.6 and 4.2 percent growth in the agricultural and non-agricultural sectors respectively (GOV, 2013). The economy of Nepal is primarily based on agriculture; about 80% of the population derives its main livelihood from farming. The 39.6 % land is under forest and 21% under cultivation. The rest is under other types of land use. Physiographically and ecologically, the country can be divided into three parts: High Himalaya 24%; the lower hills, Siwalik and mountain slopes- 56%; and the plain called Terai and inner Terai 20 % of total land. Total population in 2011 estimated about 26,494,504 showing population growth rate of 1.35 per annum with 83% rural population (GoV, 2011).

The total cultivable land of Terai and Inner Terai is 34% and of Siwalik, mountain and hill region is 8%, 10% and 48 % respectively. Most of the farmers in Terai plant timber species (*Dalbergia sissoo*, *Tectona grandis*, *Eucalyptus* etc) on terrace bunds and in hilly areas fodder species(*B. purpuria*, *B. variegata*, *A. lakoocha*, *Morus alba*, *Litsea monopetala*, *Grewia optiva*, *Ficus* sps. etc) on terrace bunds, borders and slopes of bari lands. In 1996, agriculture accounted for 42 percent of Gross Domestic Product (GDP), whereas it was 34 percent in 2008. The main agricultural exports are pulses, jute and vegetables.

Agroforestry and its importance in present context

The term Agroforestry can be defined as an intensive land use management combining trees and/or shrubs with crops and/or livestock. Within the current context, it is a suitable land-management system that increases total production, combines agricultural crops, tree crops, forest plants and or animals simultaneously or sequentially and applies management practices compatible with the cultural patterns of the local population (1989, Raintree 1990). Tree on farmland is an age-old practice but now is gaining momentum because it has a number of social, economic and ecological advantages from both the farmers and the nation's point of view. Crop production, livestock and forestry have been closely integrated and interlinked in the farming system, each supporting the other. The desired ratio between agricultural and forestlands to sustain land productivity is 1:3 (APP, 1995). The aim of developing Agroforestry technology in Nepal is to meet the present and future requirement of fuel wood, fodder, small timber, food and environmental protection in rural areas (Amatya 1999). The depletion of forest resources and increasing demand for forest products especially of the rural people who depend on forests for livelihoods have widened the gap

between the demand and supply of forest products in Nepal. Finding alternative options to increase the supply of forest products to support rural livelihoods have become a fundamental concern for policy makers and planners. Nepal's government policy emphasizes the need to initiate community and Agroforestry programs (MPFS, 1991; Shakya and Baral 2006). In light of this policy, in recent years non-government organizations (NGOs) have played a significant role in the facilitation of Agroforestry programs thereby complementing the government programs (Hegde, 1991; Regmi 2003) to meet livelihood needs of the farming households. Some successful insights observed in the leasehold forest suggest that Agroforestry has a notable potential to address dual objectives of poverty alleviation and improved degraded land (Shakya and Baral, 2006).

Furthermore, Agroforestry are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration, and that can also strengthen the system's ability to cope with adverse impacts of changing climate conditions (Verchot et al. 2007). Agroforestry options may provide a means for diversifying production systems have some obvious advantages for maintaining production during wetter and drier years. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with climatic variability.

Despite the above potentials, the promotion of Agroforestry has not been given high priority in the country's agricultural and forestry development plans (Amatya, 1999). However, farmers through experience have developed sophisticated local/indigenous knowledge base about tree-crop interaction and about the nutritive value of local fodder species (Thapa et al., 1995; Walker et al., 1998).

Agroforestry Research and Development in Nepal

There are many organizations involved in Agroforestry research and development; however, there is no clear-cut policy and program for research and development of Agroforestry system in farm land. Paudel (1997) reported that government based institutions such as Department of Forest Research and Survey (DFRS) and National Agriculture Research Council (NARC) has mandate for Agroforestry research but which institutions is responsible for what is often confusing. Furthermore, Agroforestry research is relatively new approach and location specific, the research aspect has not received much attention at policy and planning level (Baral and Shakya, 2006). In the past, limited research has been made on fodder tree selection, tree crop interaction, nutritive value analysis, propagation techniques, promotion of multipurpose tree species (MPTs) and Non-timber forest product species (NTFP). However, adaptation and application of

Agroforestry has not been fully utilized. Study shows that small farmers in the mountain region were less interested to plant tree components in the farm land due to limited land holding capacity and risk to reduce the crop yield.

Paudel (2009) further reported that rule and regulation also are complex process to sell farmlands' tree in the market. Different GOs\NGOs are mainly involved in distribution of fodder tree and grass seedlings, nursery establishment, plantation of fodder tree in degraded land and marginal land, promotion of NTFP and income generation activities for poor people through Agroforestry program (Amayta 1997, Sakya and Baral, 2006). Agroforestry research and development in Nepal so far have not produced findings that are useful to farmers; have largely ignored farmers' criteria in research design; and has been carried out with limited participation by farmers.

Agriculture and climate change

Nepal has various types of agricultural zones like plains, hills, mid hills, high hills and mountains. Changes in agro-zones lead to the change in cropping pattern of the zone. Climatic parameters have potential impact to change the ecological distribution of agricultural crops. If shifting of climatic zones occurred rapidly due to climate change, extinction of biodiversity might be severe. Effects are mainly on cold-water fish, herbs, pasturelands, tree lines (apple trees) and livestock (Yak). Malla (2008) reported that increase in temperature cause more damage on agricultural sectors in Terai region and will be more favorable to agriculture in the hills and mountains. With increase in temperature, cropping pattern as well as vector born disease of human and livestock can be expected to shift in higher eco zones too. Some lands, which are presently undesirable due to different weather factors, may be desirable in near future. For example: maize, chilly, tomato and cucumber are now being adopted in Mustang (Trans Himalayan) district of the country.

Increase in temperature may lead to reduce the level of soil organic carbon, soil micronutrients and enhance decomposition by activating the microbial population in the soil (Malla, 2003). Variability in climate and weather causes change in moisture availability in the soil. The rapid evapo-transpiration due to increase in temperature, will demand more water to reduce drought. Water availability governs the physiological active period and crop production. Research showed that evapo-transpiration and evaporation were also disturbed by +2°C and +4°C monthly temperature rise (Fennessey et al., 1994). Probable vulnerabilities due to increase in atmospheric temperature are decrease in water table, increase in evapo-transpiration, soil erosion, landslides, floods, inundation of standing crops and reduction of soil fertility. Nepal's agriculture is also facing risks due to changes in the reliability of stream flow, a more intense and potentially erratic monsoon rainfall and flooding. About 64% of cultivated areas are fully dependent

on monsoon rainfall. Decline in rainfall from November to April adversely affects the winter and spring crops. Rice yields are sensitive to climatic conditions and may fall in western region and it may threaten overall food security. The extreme weather phenomenon, including droughts and floods, is expected to induce food vulnerability to the already food insecure 3.4 million people in Nepal and this increases the cost of coping dramatically (WFP, 2009).

B.R. Regmi and A. Adhikary in 2007 reported that climate change is posing threat to food security due to loss of some local land races and crops in Nepal. NINC (2004) states that with the increase of temperature beyond 4 degree Celsius, the yield of Terai rice is projected to decrease. The effect of temperature on rice crops in the hills is little more severe than in the Terai. But in mountain region it is better, but rice is grown negligibly there. The yield of wheat is projected to fall down with the rise in temperature in Terai. The effect of temperature on wheat yield in the hills is less than in Terai. There is insignificant decline of wheat yield in mountain environment with rise in temperature. The rise in temperature will affect yield of maize crops in Terai more than wheat and rice crops. It affects less in the hills than in Terai but increases production of maize in mountain areas.

Agroforestry systems in the country and their classification

Agroforestry systems and their classification

Agroforestry system in the broadest sense encompasses a wide range of production systems, from forest to crop monoculture. The most common criteria for the classification of Agroforestry systems are the structural basis, in which components of Agroforestry (forestry, agriculture and livestock) are combined. Other criteria include its function, socio-economic scale and management level and ecological basis. The major agroforestry systems of the High Mountain and mid-hills of Nepal are home gardens, agri-silviculture system (planting trees along terrace bunds, borders and slopes), silvi-pastoral system (kharbari), agri-silvi-pastoral system (typical hill farming, in which agriculture crops are grown on terrace flat, trees on terrace bunds and borders, and grasses on terrace slopes-kanla), and alley cropping (promoted by the Leasehold Forestry and Livestock Program/FAO), where as this in Terai and inner Terai are home gardens, agri-silviculture system, silvi-pastoral system, horti-silviculture system and silvi-fishery or aqua-silviculture. Taungya system was also practiced in Terai and inner Terai of Nepal for plantation establishment. Shelter belt establishment and management practice is common in fruit orchard of Terai and inner Terai of Nepal. Apiculture, sericulture, and shifting cultivation can also be considered as minor agroforestry systems.

AF Systems involve growing woody herbaceous species and perennials in association with food crops and livestock on the same piece of land. They are

known to increase ecological diversity within a landscape unit and optimize the use of limited resources through the integration of complementary components. Nair (1989) defined Agroforestry as a land use that involves deliberate retention, introduction or mixture of tree or other woody perennials in crop/animal; production fields to benefit from the result ecological and economic interactions. Agroforestry systems of Nepal differ in socio-economic condition of the farmers and ecological zone. Some systems practiced in different ecological zones can be grouped into three principal types:

Agroforestry practice in Nepal

The word Agroforestry has been practiced in the farming systems for many generations. Farmers have cultivated trees on farm from time immemorial (Gilmour and Nurse, 1991). Agroforestry practices in Nepal can be described in two broad categories: farm –based and forest-based.

The farm-based practices are home gardens, planting trees on and around agriculture fields, tree wood lots and commercial crop under shade trees or agriculture crops inter-cropped with commercial trees. Farm based Agroforestry can further be grouped into the following categories: Tree like *Dalbergia sissoo*, *Tectona grandis*, Bamboo, and different fodder tree species found in bund and boarder sites as well as marginal land. The major land is used to cultivate different agricultural crops like paddy, millet, maize, wheat, sugarcane, tobacco, mustard etc. In many agricultural fields, farmer practiced leguminous trees such as *Leucaena*, *Sesbania* as a source of Nitrogen for fodder and green manure. Similarly, planting trees around home garden in the hills as well as the Terai is dominant practices throughout the county as a horti-silvicultural system. In this system, planting forest and fodder tree species around the home garden in the fruit tree orchard as a windbreak or multipurpose use eg. *Dalbergia sissoo* and mango/litchi etc. In eastern Nepal planting cardamom with *Alnus nepalensis* and tea with *Albezia*, *Bombex* as an under storey is commercially cultivating practices. Additionally, lopping trees and grazing understory grasses and bushes in forest and farmland area is the common practice in mountain region of Nepal as a silvo-pastoral system. In this system, fodder trees are deliberately planted around marginal land, kharbari for the production of firewood and fodder.

The forest-based practices involve specific agricultural practices, medicinal plants associated with forests where farmers collect food, fruits and gums (Tejwani and Lai, 1992). These practices involve specific agricultural practices associated with forests where farmers collect food, fruits and NTFPs. These systems emphasize forest and timber tree species generally on government controlled leasehold forest, community forest with medicinal plant, cardamum with *Alnus nepalensis*. The Department of Forests (DOF) also implemented Taungya Agroforestry system in Terai belts of Nepal to establish plantation

involving poor farmers living around plantation areas to grow agriculture crops for 3-5 years.

Association and interactions

Tree –Crop Association

Purpose of growing trees by different categories of farmers: Framing system is very complex and of subsistence type with a mutual-interdependency of crops, livestock and forest resources being integral part of farming system, just as much as arable land and livestock. Farmers depend on forest for timber, poles, fuel, fodder, litter, compost, medicinal and food plants and fruit. They intend to grow trees on their farms to meet the present and future requirements of fuel wood, fodder, small timber, for commercial purpose and environmental protection such as adverse effect of climate change.

Tree-Crop interactions: Agroforestry optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops. The benefits created by Agroforestry practices are both economic and environmental. Interactions between the tree and crop components can be positive, negative or neutral. Positive interactions can lead to an increased capture of a limiting resource, resulting in greater total output per unit area. It also helps to conserve and protect natural resources by, for example, mitigating non-point source pollution, controlling soil erosion, and creating wildlife habitat. The benefits of positive interaction also add up to a substantial improvement of the economic and resource sustainability of agriculture. Conversely, negative interactions occur when the two components overlap in their resource use, and can result in lower productivity than if the components are grown separately.

Kaushal and Verma (2003) reported that Hill farmers, irrespective of size of landholdings retain few trees on farmlands. These trees not only provide fuel wood, fruits, fodder and timber but are also helpful in bringing microclimatic changes by reducing soil and air temperature, irradiance and wind speed. However, retaining these trees normally requires a price in terms of competition for moisture, light and nutrients for the field crops. Understanding the degree of competition in these systems can provide the base line data for determining the optimum tree density, devising suitable management options and to maximize the resource use and productivity of the systems.

Perception of change in yield of different field crops grown under trees

Perception towards extraction of fodder and grass sources

People's perception towards the extraction of fodder and grasses from the community forest and the farm land were randomly assessed from 100 farmer respondents of different categories in Ilam district. Respondents generally

perceived that they gather maximum grasses and fodder from farm land compared to community forest in short time period because of the fact that community forest can be far and therefore difficult to transport such products.

Perception towards growing trees on their farm

The perception of respondents towards planting trees on their farm land was assessed by classifying the farm land as bari, khet and home garden. About 80% respondents want to have more trees on their bari land, 15% on their khet and 80% on their home garden. The reasons behind are the maximum fodder, fruit and fuel wood production from bari and home garden. Similarly, about 85% respondents do not want to have any more trees on their khet saying that it requires more labors and hence maximizes the cost per unit of land. At the same time they say that trees cast their shades and increase light, root and moisture completion with the main crops decreasing the productivity of the land.

Perception towards Agroforestry practices

The respondents were aware of the economic and environmental benefits of Agroforestry practices and had favorable attitude towards those practices. Most of the respondents agreed that Agroforestry practices increased soil fertility, increased farm income and reduced the chances of complete crop failure. The respondents realized that plantation of trees on the underutilized portion of the farmland has not decreased in the overall output of the farmland. Sequential or simultaneous production of fodder and grass, crop and vegetable and livestock contributed to increase in the overall household income. Maintenance of mixed trees on the farmland made households resilient to cope with uncertainty and risks. At the time of insect or disease outbreak in one species, they can meet their need from other species. Thus this practice has reduced the chances of complete crop failure. The respondents strongly agreed that Agroforestry practices maintained/improved surrounding condition of the forest and saved time on collecting fodder and firewood from the forest. The saved time opened up avenues for other farming activities such as vegetable farming. It is noteworthy that respondents experienced improved greenery and saw increased role of farm trees to meet their need of fodder and firewood. However they disagreed on the statement that it takes long time to get income from Agroforestry practices.

Agroforestry - Environment Linkages

Control of soil erosion

The vegetation covers and protects the soil from extreme heat and cold while slowing the natural forces of soil erosion by water, wind, and gravity. Soil sustains and increases the tree growth and provides raw materials for its life:

fallen leaves, woody debris, and dead animals recycle through the soil. Agroforestry systems like improved fallows, contour hedgerows and other systems involving permanent cover play an important role in arresting and reversing land degradation via their ability to provide permanent cover, improve organic carbon content, improve soil structure, increase infiltration, enhance fertility and biological activity.

Maintain soil fertility/ Organic matter level

Soil fertility in Nepal has been declined due to soil erosion and by burning organic matter or cattle dung as fuel wood in fuel wood shortage areas of Nepal. Average soil loss of 8–12 tones/ha/year has been reported (Carson, 1992). The decline in vegetative covers of grasses, trees and shrubs has been considered to be the main factor contributing to topsoil erosion. Soil erosion and excess removal of surface cover and crop residues from farm lands pose serious constraints to land management and sustaining agricultural production in the hills (Schreier et al., 1995; CBS, 1998) of Nepal. Therefore Agroforestry practice needs to be promoted through the plantation of leguminous fodder and forage species. Finally, the promotion of Agroforestry systems with the combination of legume and non-legume tree and crop species not only improves and sustains soil fertility, but also reduces soil erosion and land degradation.

Nutrient recycling

Nutrient recycling from the soil is a common Agroforestry hypothesis. Deep-rooting trees can absorb leached nitrate and other nutrients from the subsoil, which depend on trees and crop species, climate and soil conditions. Deep nutrient capture by trees increases total nutrient availability in the system. Fallen leaves, twigs, flowers and fruit, and crop residues etc help to add organic matter and humus into the soil, which also increase microbial activities in the soil. Soil microorganisms are decomposers that break down organic matter into humus and plant available nutrients and cycle nutrients back to plants, starting the cycle over again. A favorable effect of deep nutrient uptake is most likely to occur in the case of leguminous trees and crops, whose nutrient-rich leaf and branch biomass is regularly returned to the soil as pruning debris, fallen leaves etc. These species also accumulate nitrogen in roots. However, if these trees are more competitive in the topsoil with agriculture crops, their integration into a cropping system will reduce nutrient availability rather than increase, even if the trees are deep-rooting. Therefore, trees having deep roots with few lateral roots should be selected.

Biological reclamation of saline and alkali soils

Soil salinity is a measure of the total amount of soluble salt in soil. As salinity levels increase, plants extract water less easily from soil, aggravating water stress

conditions. High soil salinity can also cause nutrient imbalances, result in the accumulation of elements toxic to plants, and reduce water infiltration if the level of one salt element--sodium--is high. In many areas, soil salinity is the limiting factor for plant growth. Salt-affected plants are stunted with dark green leaves which, in some cases, are thicker and more succulent than normal. In woody species, high soil salinity may lead to leaf burn and defoliation. High salinity causes alfalfa yield to decrease while the leaf-to-stem ratio increases, influencing forage quality. Grasses also appear dark green and stunted with leaf burn symptoms. Salinity tolerance is influenced by many plant, soil, and environmental factors and their interrelationships. Generally, fruits, vegetables, and ornamentals are more salt sensitive than forage or field crops. In addition, certain varieties, cultivars, or rootstocks may tolerate higher salt levels than others. Plants are more sensitive to high salinity during seedling stages, immediately after transplanting, and when subject to other (e.g., disease, insect, nutrient) stresses.

Shelterbelt and Windbreak

In Nepal, shelter belts and or wind breaks are maintained in Terai and inner- Terai regions where strong hot and dry wind damage agriculture crops and fruits. For the establishment of effective shelter belts or wind breaks, 1-2 rows of trees are planted at 1-2 meters row to row distance and 2-3 meters plant to plant distance maintaining 35-50% porosity from top to bottom. Tree species selected for shelter belt should be deep rooted, nitrogen fixing, well branched with straight stem, moderate to dense wind breaking capacity, produce high demanding valuable products etc. *Eucalyptus camaldulensis*, *Casuarina equisetifolia*, *Dalbergia sissoo*, *Acacia auriculiformis*, *Melia azaderach*, *Leucaena leucocephala* and *Bambusa species* are mostly planted as wind break and or shelter belt.

Biodiversity conservation

Agroforestry is increasingly being acknowledged as an integrated land use that can directly enhance agro-biodiversity and contribute to the conservation of landscape biodiversity, while at the same time increase, diversify and sustain rural incomes as well as reducing habitat loss and fragmentation. Agroforestry practices may provide to local and even global society by maintaining watershed functions, retaining carbon in the plant–soil system, and, most recently, by supporting the conservation of biological diversity (Mc Neely and Scherr 2002; Schroth et al. 2004). It is an insitu agrobiodiversity conservation technique. Furthermore, Schroth et al. (2004) identified and discussed three roles of Agroforestry in biodiversity conservation on a landscape scale:

- The provision of supplementary, secondary habitat for species that tolerate a certain level of disturbance;

- The reduction of rates of conversion of natural habitat in certain cases;
- The creation of a more habitat remnants compared with less tree-dominated land uses, which may support the integrity of these remnants and the conservation of their populations.

Traditional Agroforestry practices benefit biodiversity through in-situ conservation of tree species on farms, reduction of pressure on remaining forests, and the provision of suitable habitat for plant and animal species on farmland. Agroforestry systems maintain a level of biodiversity that is lower than that of the original forest but higher than that of monocultures, and that they provide suitable habitat for a number of forest-dependent species.

The Agroforestry practices including alley cropping, windbreaks, forested riparian buffers, silvo-pasture and forest farming provide opportunities to manage for a diversity of plant communities and habitats that have the potential to benefit the wildlife resource. Agroforestry can also provide the means that enables landowners to improve habitats for wildlife on their property while offering alternative sources of income to the farm. A number of recently completed review papers suggest ways in which Agroforestry contributes to the conservation and protection of biodiversity, including that of both wild species and species more directly related to agricultural production (Boffa 1999; McNeely 2004).

Poverty alleviation

Agroforestry in Nepal can greatly improve livelihood of farmers providing multiple products from same piece of land at the same time. It is a popular system in our society due to its ecological and economical benefits. The most common existing Agroforestry systems practiced in mountain and high Himalayan areas of Nepal are agri-silvo-pastoral system, which is followed by agri-silviculture system, silvi-pastoral system (Kharbari) and multipurpose home gardens. Similarly, the common Agroforestry models of Terai and Inner Terai are Home gardens followed by Agri-silviculture, Horti-silviculture and Aqua-silviculture systems.

The Department of Forests (DOF) also implemented Taungya Agroforestry system in Terai belts of Nepal to establish plantation involving poor farmers living around plantation areas to grow agriculture crops for 3-5 years. Agroforestry system has also positive impacts on conserving soils and moisture, improving soil fertility and stabilizing sloppy lands etc. It is an integrated farming systems which provides multiple products such as food, fruits, fodder, forage, fuel wood and timber etc needed for farmer's day to day life. Government of Nepal identified Agroforestry as poverty reduction programme, which can be carried out under government as well as private lands. Agroforestry systems link rural people

with forests, trees, and the products and benefits to be derived from them. Farmers raise forage and NTFPs like:

- Cardamom under *Alnus* trees in community forests and on the farm lands
- NTFPs like in community forests and on the farm lands
- Ginger farming in leasehold forest and on the farm lands
- Fruit trees and NTFPs in leasehold forest and on the farm lands

Agroforestry -Farming systems Linkages

Trees, crops, and livestock are the integral components of the complex Nepalese Hill Farming System. Agroforestry practice in Nepal has helped millions of farmers to generate the cash income through forest products such as firewood, fodder, Non-Timber Forest Products (NTFPs), etc. and enhance wild biodiversity by conserving the habitat of wild birds and animals. It is self-sustaining in nature. It has already been proved as the most successful land use system in fragile Hill and Mountain areas of Nepal, which has helped to increase the productivity and maintain ecological stability. The role of Agroforestry in sustainable Hill and Mountain agriculture can be easily understood by interrelationship and interdependence of crop, livestock and forestry sector in the typical Nepalese Hill Farming System. Carson (1992) found out that Nepalese Hill farmers use on average 10-20 tons of compost manure per hectare of rain fed Bari land, which is achieved through transfer of nutrients from forest and grasslands via livestock (Parajuli, 1999).

Subsistence agriculture with a strong link to forestry is the main basis of livelihoods in the region. There are complex and inseparable relations between forests, agriculture and human subsistence (Mahat 1987). The local farming systems heavily rely on forest and trees for their sustainability. Trees are the single most important source of fodder for livestock, which in turn provides draught power for cultivation, food products such as milk and meat, and maintains soil productivity through compost and manure.

Farmers in the hills have responded to deforestation by increasing the number of trees on their farms to meet their demand for tree products (Carter and Gilmour 1989). In this process, farmers have influenced the dynamics, diversity and genetic makeup of farm tree populations through planting and domestication. In subsistence hills agriculture, there exists a complementary relationship among trees, crops and livestock, where trees and crops provide fodder and bedding materials to livestock and in turn livestock provide draught power, milk, meat and manure. Animal manure combined with large quantities of forest products collected for animal bedding and fodder accounts for a considerable proportion of nutrient supply to crops (Yadav, 1992). However, hill farmers have increasingly

been confronted with a decline in forest fodder supply due to steadily increasing livestock population, deforestation and uncontrolled livestock grazing in forests (Mahat, 1987).

Several studies indicate improvements in tree growing on the private farmlands to compensate the loss of trees in the forest (Thapa et al., 1994; FSD/FRISP, 1999). The declination in forest cover has been associated with increased soil erosion, fertility degradation in soil, and reduced agricultural productivity. There is growing evidence that Agroforestry can be a promising solution to these problems (Carter and Gilmour, 1989) and hence a key to the sustainability of the hill farming system.

Many studies have explored the role of these types of trees in the sustainability of agriculture (Mahat, 1987; Carter and Gilmour, 1989; Carter 1991). In addition, the role of agricultural systems for the conservation of crop diversity has also been studied (Jha et al., 1996; Joshi et al., 1996; HMGN, 2002). Despite the above potentials, the promotion of Agroforestry has never been given high priority in the country's agricultural and forestry development plans (Shah, 1996). However, farmers through experience have developed sophisticated local/indigenous knowledge base about tree-crop interaction (Thapa et al., 1995) and about the nutritive value of local fodder species (Thapa et al., 1997; Walker et al., 1999). In the past, no particular attention was directed toward Agroforestry research and innovation, resulting in a lack of appropriate Agroforestry practices for farmers (Tamang, 1991; Carson, 1992; Shrestha and Katuwal, 1992). However, in recent years there has been growing concern over the importance of Agroforestry to sustaining the hill agriculture and some efforts are being made to promote Agroforestry at the farm level. However, the role of farm trees for biodiversity conservation and meeting rural household needs has received little attention.

Intercropping

Intercropping is a multiple cropping practices involving growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Careful planning is required, taking into account the soil, climate, crops, and varieties. It is particularly important not to have crops competing with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade.

When crops are carefully selected, other agronomic benefits are also achieved. Lodging-prone plants are those that are prone to tip over in wind or heavy rain may be given structural support by their companion crop. Creepers can also

benefit from structural support. Some plants are used to suppress weeds or provide nutrients. Delicate or light-sensitive plants may be given shade or protection, or otherwise wasted space can be utilized.

An example is the tropical multi-tier system where coconut occupies the upper tier, banana the middle tier, and pineapple, ginger, or leguminous fodder, medicinal or aromatic plants occupy the lowest tier.

Intercropping of compatible plants also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single-crop environment. This in turn can help limit outbreaks of crop pests by increasing predator biodiversity. Additionally, reducing the homogeneity of the crop increases the barriers against biological dispersal of pest organisms through the crop.

Homestead Production System

In Nepal, the Ghar Bagaincha, literally "home garden", refers to the traditional land use system around a homestead, where several species of plants are grown and maintained by household members and their products are primarily intended for the family consumption (Shrestha et al., 2002). In Nepal, 72% of 3households have home gardens of an area 2–11% of the total land holdings (Gautam et al., 2004). Because of their small size, the government has never identified home gardens as an important unit of food production and they thereby remain neglected from research and development. However, at the household level the system is very important as it is an important source of quality food and nutrition for the rural poor and, therefore, are important contributors to the household food security and livelihoods of farming communities in Nepal. The gardens are typically cultivated with a mixture of annual and perennial plants that can be harvested on a daily or seasonal basis. Biodiversity that has an immediate value is maintained in home gardens as women and children have easy access to preferred food, and for this reason alone we should promote home gardens as a key element for a healthy way of life. Home gardens, with their intensive and multiple uses, provide a safety net for households when food is scarce. These gardens are not only important sources of food, fodder, fuel, medicines, spices, herbs, flowers, construction materials and income in many countries, they are also important for the in situ conservation of a wide range of unique genetic resources for food and agriculture (Subedi et al., 2004). Many uncultivated, as well as neglected and under-utilized species could make an important contribution to the dietary diversity of local communities (Gautam et al., 2004).

In addition to supplementing diet in times of difficulty, home gardens promote whole-family and whole-community involvement in the process of providing food. Children, the elderly, and those caring for them can participate in this infield

agriculture, incorporating it with other household tasks and scheduling. This tradition has existed in many cultures around the world for thousands of years.

Agroforestry technologies

Agroforestry techniques are a suite of land management practices for maintaining or increasing agricultural productivity while preserving or improving fertility and maintaining some level of plant cover. They involve deliberate retention, introduction or admixture of trees, or other woody perennials, in crop/animal production fields to benefit from the resultant ecological and economic interactions (Schroeder, 1993). A typical Agroforestry system allows synergistic interactions between woody and non-woody components to increase, sustain, and diversify total land output (Swaminathan, 1987; Schroeder, 1993). Thus, while agricultural production continues, wood needs are met and continuous carbon sequestration for the purpose of mitigating climate change is put in place.

Agroforestry technologies adopted in Leasehold forests of Nepal

Agroforestry is a popular land use activity on leasehold forests in Nepal. After protecting forestland from grazing and fire, bushes and undesirable species are removed. This aims at creating further room and favorable environment for natural regeneration either from trees in neighboring forests, stumps, root suckers/runners/rhizomes, seed-bank (existing potential germination capacity buried seeds in soils) or more rarely, seeds from existing young trees in the leasehold forestland. The forest users build trails or footpaths, which also help in fire protection. Horticultural and pasture species have been planted to fill the big gaps. Type and density of species combination depends on leasehold families' preference on species and nature of ecological need of the species to suit in the existing gaps between trees. For example, in many leasehold forests, strong light demanding lemon grass was introduced in open gaps, whereas forage species, such as stylo (*Stylosanthes guinensis*) was planted in smaller gaps in between trees as these forage need less light compared to lemon grass. Multipurpose tree species, *Artocarpus lokoocha* was introduced as an enrichment plantation; nitrogen fixing *Leucaena* sp. and molasses (*Melinis minutiflora*) were planted in open deteriorated micro-sites to enrich soil. For the first two years, tree seedlings were smaller and were surrounded by pasture species. As seedlings attained height, pasture species did not spread close to tree seedlings growing instead only in-between the tree rows. There is no fixed geometrical configuration for plantation, and hence species have been introduced following the presence of existing natural tree patterns. Trees have been planted in rows, and perennial pasture species have been introduced as understory ground cover between tree rows in completely bare forest lands. The most common forms of Agroforestry

practiced in the leasehold forestlands of Nepal can be classified under two categories of forests:

Natural Forest:

- Shorea robusta forest with horticultural crops as an understory crop i.e., turmeric, ginger, pumpkin, soybean, yam and lemon grass.
- Sal forest with perennial pasture species on ground cover, i.e., stylo, molasses and napier.
- Sal forest with perennial tree fodder species, ie, *Artocarpus lokoocha*, *Bauhania sp* and mulberry, in small blocks.
- Sal forest with perennial tree fodder species, i.e., *Artocarpus lokoocha* in small blocks with perennial pasture species on groundcover, i.e., stylo and molasses or local pasture species.
- Sal forest with perennial tree fodder species, i.e., *Artocarpus lokoocha* in alternative lines or scattered.
- Sal forest with fast growing short rotation fire wood species with less potential for fodder, i.e., *Albizia lebbeck*, and *Leucaena* in alternative lines or scattered.

Plantation Forest:

- Mixed tree species for multipurpose products i.e., *Melia azedarach*, *Dalbergia sisso*, and *Leucaena* with ground cover perennial pasture species, i.e., stylo and molasses.
- Fast growing nitrogen fixing tree, i.e., *Alnus nepalensis* with napier grass in gullies.
- Fast growing multipurpose trees, i.e., *Melia azaderach*, *Leucaena* with lentils i.e., black gram and pigeon peas.

Agroforestry technologies adopted by ICIMOD and NARC

In Nepal, the International Centre for Integrated Mountain Development (ICIMOD) and the National Agriculture Research Council (NARC) have been instrumental and active in testing various SALT options over the last few years and have found that these technologies are effective in conserving soil and water, enhancing soil fertility and increasing crop production.

SALT 1: This model focuses mainly on food crop production. It is simple in application, low in cost, but is an effective Agroforestry technology with agricultural crops and forestry in a ratio of 3:1. Compared to traditional upland farming management practices, this technology substantially decreases erosion. In addition, it increases crop yield.

SALT 2: This model focuses on agro-livestock technology. It is a simple modification of SALT I in the sense that it integrates livestock rearing with crop cultivation. The livestock species that can be raised under the system are cattle, sheep, and goats. The manure is a good source of fertilizer. Goats (the poor man's cow) are a potential source of milk, meat, hair and skin.

SALT 3: This focuses on the conversion of non-productive marginal land into economically productive land to supplement production from other SALT models. This model has three components: SALT I, SALT II, and a separate plot of land to produce valuable timber. Farmers owning landholdings of about two hectares can use this model

SALT 4: This focuses on developing a horticulture and plantation crop-based system known as the agro-fruit livelihood technology. To improve hill agriculture and economics, commercialization of hill agriculture is required. Thus, horticulture is a promising option with comparative advantages. The objectives of this model are to produce food, increase cash income, and conserve soil on farmlands.

Agroforestry Potential as CSA technology

Gurung (2012) reported that increase in temperature had been about 0.04°C/year in Terai and 0.08°C/year in the high mountains of Nepal. Monsoon has been erratic in the country with late or early onset and decrease in number of rainy days. Too little or too much of rain is resulting in drought or flood resulting in severe losses to agricultural productivity. Number of rainy days with high intensity (>100 mm rain/per day) has been increasing in recent past. Soil moisture availability has been reduced resulting in early maturing of crop, crop failure and reduction in productivity. Extreme fog conditions and cold wave in the Terai region in winter are affecting winter crops in the country. He suggested to follow CSA which included multiple cropping (inter-cropping, mixed cropping, sequential cropping, relay cropping, Agroforestry), terraced cultivation in hills, conservation of agro biodiversity (in situ and community gene bank), integration of legume in cropping system and utilization of plant and animal waste (crop residues, compost, FYM, biogas slurry) in agriculture. The practices such as organic and integrated farming system, farmers' managed irrigation system, crop residue mulching and indigenous knowledge should be promoted as a part of CSA.

The Nepalese farmers are most vulnerable to climate change due to their smallholding and rain fed agriculture. However, the adoption of CSA technologies including drought, submergence and disease tolerant varieties of crops is increasing. Some Agroforestry potentials which are being adopted as CSA technologies in the country are:

Agro-silvicultural Potentials

It is defined as growing of trees and agriculture crops together in same lands at the same time. This system is common in all agro-ecological zones of Nepal, where agriculture crops are grown in terrace flat and trees are grown in terrace bunds, borders and slopes. Trees grown in different regions are Terai (*D. sissoo*, *Eucalyptus*, *Melia azaderech*, *Leucaena* etc) hill (Mainly fodder trees such as *Artocarpus lakoocha*, *B. purpuria*, *B. variegeta*, *Leucaena*, *Morus alba* etc) and mountain fodder trees such as *Saurauia nepaulensis*, *Ficus* etc. The main advantages of this system are as follows:

Produce multiple products such as food/vegetables/fruits, fodder and forage needed for livestock, fuel wood, timber, and leaf litter needed for organic manure production.

- Improve and sustain the crop productivity which increases the level of income of the farmers.
- Improve the nutritive value of animal feed due to the supply of green fodder.
- This is also the best practice for soil nutrient recycling, which also helps to reduce chemical fertilizer purchase.
- Improve the farm site ecology by reducing surface run off, soil erosion and nutrient loss, gully formation and landslides.
- Improve the local micro-climate and enhance the productive capacity of the farm.
- Reduce pressure of community forests and other natural forests for fodder, fuel wood and timber.
- This practice helps for the beautification of the surrounding areas. Inter cropping practices can also adopt in this system in plain areas where trees should be grown maintaining rows to rows distance (5 meters) and plant to plant distance (2-3 meters). Management operations such singling, pruning and thinning in timber species and lopping, coppicing and pollarding in fodder species should be applied to reduce shading effects of trees on agriculture crops.

Silvi-pasture potentials

This system can be defined as growing of trees and grasses or forage species together in same lands at the same time. This system is common in all agro-ecological zones of Nepal, where land is marginal for crop production. In mid-hilly region, land having grasses is known as kharbari.

Trees grown in kharbari in different regions are Terai (*D. sissoo*, *Eucalyptus*, *Leucaena* etc), hill (mainly fodder trees such as *A. lakoocha*, *B. purpuria*,

B.variegata, *Leucaena* etc and timber species like *Schima walichii*) and mountain (fodder trees such as *S. nepalensis*, *Ficus* *sps.*, *Quercus* *sps.* etc. The main advantages of this system are as follows:

- Produce multiple products such as fodder and forage needed for livestock, fuel wood, timber, and leaf litter needed for organic manure production.
- Improve and sustain the livestock productivity which increases the level of income of the farmers.
- Improve the nutritive value of animal feed due to the regular supply of green fodder.
- This is also the best practice for soil nutrient recycling, which also helps to reduce chemical fertilizer purchase.
- Improve the farm site ecology by reducing surface run off, soil erosion and nutrient loss, gully formation and landslides.
- Improve the local micro-climate and enhance the productive capacity of the farm.
- Reduce pressure of community forests and other natural forests for fodder, fuel wood and timber.
- This practice helps for the beautification of the surrounding areas.

Agro-silvi-pastoral system

Growing of trees, agriculture crops and grasses together in same lands at the same time is known as agro-silvi-pastoral system. This is typical hill farming system of Nepal, in which agriculture crops are grown in terrace flat, trees in terrace bunds, border and slopes and grasses in terrace slopes.

Horti-silviculture system

This system is defined as growing of trees and fruit trees or ornamental trees or vegetables/flower together in same lands at the same time. This system is common in Terai and Inner Terai of Nepal, where trees such as Sissoo, Eucalyptus, *Melia azaderech*, *Leucaena* species etc are grown around fruit orchard that act as shelter belt. In eastern Nepal, cardamom is planted as an under storey with *Alnus nepalensis* trees. Similarly, Albizia and Sissoo trees are planted for providing shade to tea, and *Leucaena* is the best trees



Figure 1 Agro- silvi-pastoral system in hills of Nepal

for providing shade to coffee plants. The main advantages of this system are as follows:

- Produce multiple products such as fruits, fodder and forage needed for livestock, fuel wood, timber, and leaf litter needed for organic manure production.
- Improve and sustain the fruit/vegetable productivity which increases the level of income of the farmers.
- This is also the best practice for soil nutrient recycling, which also helps to reduce chemical fertilizer purchase.
- Improve the farm site ecology by reducing soil erosion and nutrient loss.
- Improve the local micro-climate and enhance the productive capacity of the farm.
- This practice helps for the beautification of the surrounding areas.



Figure 2 Cardamom cultivation under A. nepalensis in hills

Silvo-fishery or aqua-silviculture

Growing of trees around fish pond is known as silvo-fishery or aqua-silviculture. In this system, trees and fruit trees are being planted along the embankment of the fish pond. This system is popular in Terai and inner-Terai of Nepal, where trees and fish included in the same system. Tree species grown along the embankment of fish pond are *D. sissoo*, *Eucalyptus*, *Melia azaderach*, *Leucaena* species etc and fruit species are Banana, Papaya and Pine apples. Some farmers also included duck and pigs in aqua-silviculture systems. The main advantages of this system are as follows:

- Extra income can be generated from trees, fruits ducks and pigs.
- Tree grown along the embankment of the fish ponds create cool environment to fish during summer season providing shade.
- Leaves, flowers, and fruits fallen into the fish pond can provide food to fish.



Figure 3 Aqua-silviculture practice in Terai

Multistorey Agroforestry

It means multi-tier crop cover, in which tallest species like coconut, Eucalyptus and other tree species are grown that is followed by banana, papaya, pineapple, coffee etc. Ginger, turmeric, pepper, yam and colocasia are the ground tier crops.

While designing this 3 tier system, level of organic matter and mineral content into the soils should be considered. This system improves the productivity and conserves the environment. It also controls soil erosion, moderates surface soil temperature, suppresses weeds, recycles nutrients and preserves moisture.



Figure 4 Multi-tier cropping under Eucalyptus

Alley cropping

It is also known as hedge row intercropping, and involves managing rows of closely planted woody trees with annual crops grown in alley in between hedge rows. Woody plants are cut regularly, and leaves and twigs are used as mulching materials on the alley cropping areas for reducing evaporation from soil, control weeds and add nutrients and organic matter into the soil. Increase crop yield due to the addition of organic matter into the soil.



Figure 5 Alleycropping under high tension line passing through forest

Legume plants like Leucaena are grown on the hedge rows which fix nitrogen into the soil. Hedge rows give products like fruit, fodder, leaf litter, fuel wood poles. This system is generally practice in sloppy lands which helps in reducing soil erosion. The position and spacing of hedge rows and crops plants in alley cropping system depend on plant species, climate, slope, soil condition and space required for the movement of people and tillage equipment. Hedge row distance should be maintained 4-8 meters and plant to plant distance from 25 cm to 2 meters. Hedge rows should be developed across the slope of the land.

Trees in and around the agricultural fields

This is the common practice found in both bari and khet land of the study area. Fodder trees are planted in the terrace rises, and abandoned land inside the bari land and timber trees were raised in the border of the land, near the streamlets, landslide areas and near to the forest and grass species in sloppy riser and bund of terrace edge and annual crops; maize, millet on terrace in the bari land.



Figure 6 Alleycropping under Eucalyptus trees

Public land Agroforestry

The ministry of Forest and Soil Conservation started the public land Agroforestry programmes in Terai for (i) bringing the barren/useless/parti lands which are under ownership of public institutions like

VDC/Schools/Roads/irrigation and other in use as Agroforestry farmlands, (ii) involving poor/Dalit/women in public land Agroforestry groups for their livelihoods improvements by selling agricultural as well as forest crops and (iii) fulfilling, up to some extent, the

forest products need of Terai people. The aim of the public land forestry/Agroforestry in the Terai is to enhance the livelihood opportunities of resource poor households and communities through equitable productive and diversified management of such lands.

The contribution of Public land Agroforestry for rural livelihoods: a case of Dhanusha district is presented below:

In Dhanusha district, there are 101 VDCs and 1 Municipality. Out of 101 VDCs, only 12 VDCs are located near the national forests. Accordingly, majority of population reside away from forests and they have no access to the resource base. Dhanusha DFCC decided to promote private and public land Agroforestry programmes in those areas away from national forests. Public lands are the lands owned by public institutions like School, VDCs or other government owned lands with public use rights. Such lands are generally fallow and useless. These lands are used as playing grounds, grazing lands or used for other purposes in the



Figure 7 Public land Agroforestry

respective communities. Increasing rate of population has limited the land holding capacity and the capacity being decreased day by day. In such scenario, each and every piece of land is to be utilized at its maximum capacity. For this, altogether 19 Public Land Agro forestry Groups have been formed. They all have planted tree species on their public lands as major component of Agroforestry practices. These plantations help to uplift socio- economic conditions of involved poor HHs. Also they have planted Eucalyptus as major species. The other tree species planted are: *Gmelina arborea*, *Albizzia* species, *Bombax ceiba*, *Ceiba pentandra*, *Tectona grandis*. They chose Eucalyptus for its fast growth and high market potential. Further the pole sized Eucalyptus is very useful for house making purpose. Thus they have both options to sell products at village level or to outsiders. According to group members, they can easily sell at NRs. 1000/- to NRs 1500/- per pole of age between 7-10 years.

Hence, Public Land Management program help to uplift the socio-economic conditions of involved poor households. However, there is still a debate in land ownership vs. tree ownership in public lands.

Shifting Cultivation

Shifting cultivation is a traditional farming system in the middle mountains of Nepal. The return period of this practice is 3-10 years. This practice is discouraged as a cause of deforestation and other environmental problems like water induced disasters, wildfire etc. The system is still practicing as there is no alternative to many poor people for their subsistence. To overcome this problem, broom grass and suitable tree species has been planted to reclaim the exposed sites and to generate income of the farmers.

Other potentials

Water management

Agroforestry systems have been recommended for decreasing soil erosion caused by surface runoff. Surface runoff can occur when the rate of precipitation exceeds the rate of infiltration of water into the soil surface. It can be reduced by the interception of water by plant canopies and plant litter, which can decrease the amount, the intensity and the spatial distribution of the precipitation reaching the soil surface. Interception of rainfall by plants and litter protects the soil surface from the direct impact of raindrops which can cause breakdown of the soil structure, leading to sealing of the surface and large reductions in surface infiltration rates (K. S. Reddy adapted from Marshall et al., 1996). Rain water harvesting ponds and irrigation channels constructed in rain fed Chuiya-bhabar areas are some examples of water management for ground water recharge, irrigation and livestock drinking.

Land reclamation

Land degradation is also a serious problem in Nepal. It is caused by deforestation, faulty agricultural practices and soil erosion. Degraded lands can be deserts, gullied lands, salt affected lands, alkaline and acidic lands, fallow lands, surface water logged lands and other lands lying unutilized. These lands can be brought under vegetative cover with some

reasonable efforts such as soil and water management. The use of these lands for agriculture purposes requires large inputs and has a very limited scope. However, these lands could easily be developed through Agroforestry practices by introducing suitable legume and non-legume trees, fodder/forage and agriculture crops. Therefore, Agroforestry systems are one of the best options to overcome these problems of land degradation.



Figure 8 Agroforestry practices for soil conservation

Constraints to up scaling Agroforestry

Major constraints to up scaling Agroforestry systems in Nepal generally fall into the following categories: biophysical, technical, economic, social and cultural, institutional and infrastructural, which are briefly discussed in following section:

Biophysical constraints: The major biophysical constraints are small size land holdings with low soil fertility, limited or irregular water resources, and limited arable land of suitable soil types and less leveled or hilly topography.

Technical constraints: The main technical constraints include the lack of technical know to farmers on Agroforestry seedling production and plantation management techniques, lack of commercially viable short duration tree species, and lack of Agroforestry enterprise management techniques.

Social constraints: The declining status of agricultural and Agroforestry employment provide social constraints to resource management in Agroforestry systems.

Economic constraints: The major economic constraints consists the poor farmers with small size of land holdings, lack of money or credit facility to establish and manage Agroforestry plots, problem of Agroforestry products transportation and marketing (problem in getting forestry products transportation license), low access of Agroforestry farmers to the end markets (middle man gets most of the benefit of Agroforestry products), migration to cities and other countries for jobs and emigration opportunities, high cost of imported livestock feed, chemical fertilizers and other inputs, tourism opportunities, the relatively high value of

agricultural lands in areas where transportation facilities are available, and commercial real estate uses of farmland lands.

Cultural constraints : Land tenure systems characterized by fragmented land holdings and land use rights of some of the so-called private lands which have no land ownership certificate can be primary cultural constraints to commercial development of Agroforestry systems.

Institutional constraints: There is no coordination mechanism between the Department of Forests, Agriculture and Livestock Services to provide technical and other supports needed for Agroforestry plot establishment and resource management in Agroforestry systems.

Infrastructural constraints: Lack of rural roads, and farm roads in mountain and high Himalayan regions of Nepal, scarcity of transportation from rural and outlying areas to central markets, and costly and problematic transportation to international markets

Potentials for improvement

Since Agroforestry promotion program has been given less attention and research findings also do not meet so far farmers' requirements, so there is a need to enhance Agroforestry technologies among the farmers by developing mechanisms to link farmers' interest and scientist's knowledge; proven to yield significantly and immediate economic benefit to farmers. Agro-forests supply fodder and fuel wood more than community forest in Nepal. Resource poor heavily rely on forests for forest products used for livestock rearing, cooking and household construction. For the self-dependency of timber from agro-forest, plantation of suitable timber species is urgently needed. Some policies regarding APP (1995), NBS (2002) and Interim plans have been formulated to promote Agroforestry program in the country to achieve the targeted national goals of improving livelihood support in lessening rural poverty. Likewise, the government has also emphasized to institutionalize the Agroforestry program by establishing Agroforestry branches and divisions under the DoA and DoF. Likewise, an understanding has been recently signed by two ministries to enhance the Agroforestry programme. Appropriate management plan along with selection of compatible species of trees to enhance the productive capacity of land needs to be formulated. There is a need to link Agroforestry system to improve livestock based production system (there is huge contribution of Community F and LF in reducing poverty in Nepal by promoting livestock) by supplying green fodder and forage during feed shortage periods.

Conclusions

Farmers of Nepal have been practicing different agroforestry models in different geographical location. Agroforestry supplies fodder, fuel wood, timber and fruit for rural household consumption. Home garden, hedgerow intercropping, trees in and around the agricultural fields, grasses with trees in kharbari land are the common Agroforestry practices in Nepal. The integrity of crop, livestock and forestry components to fulfill the livelihood needs of resource poor farmers and maintain the ecological stability is obvious in farming system. The linkage of these three components has enabled the Nepalese farmers to survive throughout the history. It reveals that agroforestry innovations provide options for reducing poverty, improving food and income security and sustaining environmental quality. Degradation of the forest resources and increasing demand of the forest product posed the great challenges to sustain the rural livelihoods. Moreover, agroforestry management systems offer an important opportunity for creating synergies between actions undertaken for mitigation and activities undertaken for adaptation on climate change that also provide opportunities to increase the resilience of agricultural systems. In this context, promotion of the agroforestry technologies in rural farming is an important component to improve rural livelihoods and for environment conservation. Similarly, appropriate policies are still needed to enhance agroforestry practices.

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Chapter 8

Technological advancement in agro-forestry systems: strategy for climate smart agriculture technologies in Pakistan

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Abstract

Agriculture is the backbone of the economy of Pakistan employing over 47% of its population, contributing 24% to GDP, providing largest source of foreign exchange earnings and meeting raw material needs of country's major industries. On the other hand, Pakistan is regarded as a country with very low forest cover having with only 0.03 ha of forest per capita as compared to the world average of circa one ha. More than 90% of the fuel wood and 55% timber requirements of the country are met through agroforestry. Expansion in the area of public forests is not possible; however there is a vast scope of growing trees on agricultural land. Pakistan is rated among the top 10 most vulnerable countries to climate change. Agroforestry can provide synergy between mitigation as well as adaptation. Agroforestry has the potential to meet the challenges of climate change both through mitigation (carbon sequestration) and adaptation in terms of soil and water conservation, through provision of permanent cover, sustainable diversification of agricultural systems and incomes, moderating the microclimate, enhance the use efficiency of rain water, provide economically viable and environmentally friendly means to improve soil fertility.

Important agroforestry systems and practices in Pakistan include, Agrisilvicultural Systems, Silvopastoral System, Agrosilvopastoral System, Apiculture, Aquaforestry and Woodlots. In Pakistan, the impact of climate change has only been studied on main annual cereal crops only. It is recommended that a detailed survey of the existing agroforestry systems be carried to redefine the systems in view of soil conditions, climatic conditions and socio-economic limitations. Detailed studies on the competition and complementarity between trees and crops for sunlight, space and soil recycling of nutrients are needed to be explored. Future breeding programme may focus on screening of trees for light, heat along with screening of crops which can tolerate and high relative humidity. Lastly there is a need to study the socio-economic constraints and short-term and long-term benefits of farmers may be ensured.

Introduction

Pakistan is by and large an agricultural country, with over 47% of its population earning their livelihood from agriculture. This sector contributes 24% to GDP (Economic Survey of Pakistan, 2013). It is the largest source of foreign exchange earnings and meets raw material needs of country's major industries. The growth in the agriculture sector increased from 0.6% to 1.2% during the recent past. The Indus Valley, which is the cradle of Pakistan's agriculture, is currently under threat by climate change which is largely induced through anthropogenic interventions resulting in global warming. While higher concentrations of carbon dioxide can have some positive effect on crops, rising temperatures and reduced precipitation can play havoc with the biological complex (IUCN, 2009).

Improved growth in agriculture sector is attributed to the government's agricultural policy reforms such as waiving of interest on loans, support price policy of wheat and introduction of micro credit facility. The growth is also attributed to timely measures to get cotton out of deep-seated crisis. Wheat is the principal food and commercial crop and occupies about 37% of the total cropped area.

Table 1: Growth Rate of Agriculture Sector (%)

Item	2011-12	2012-13		2013-14	2012-13
	Actual	Target	Achievement	Achievement	% of GDP
Crops	2.9	4.0	3.6	3.8	8.67
Livestock	3.9	4.2	3.7	3.9	11.88
Fisheries	1.7	2.0	0.1	2.0	0.44
Forestry	3.8	2.0	0.7	2.0	0.44
Agriculture	3.5	4.0	3.3	3.7	21.4

Source: Pakistan Bureau of Statistics and Planning Commission of Pakistan.

Geographical area of Pakistan stretches over of 87.98 million ha including 4.57 million ha under forests, which is about 5.2 percent of the total land area (Table 2).

Table 2. Forest area as percentage of the total area in Pakistan

Province	Total area (‘000 ha)	Forest area (‘000 ha)	Percentage
NWFP	10 170	1 410	13.9
Azad Jammu Kashmir (AJK)	7 040	770	11.0
Balochistan	34 720	720	2.1
Sindh	14 090	680	4.8
Punjab	20 630	630	3.1
Northern Areas	1 330	360	27.0
Total/average	87 980	4 570	5.2

Source: Pakistan National Forest Policy, 2010

Pakistan is regarded as a country with very low forest cover with only 0.03 ha of forest per capita as compared to the world average of circa one ha. The contribution of forestry sector in the Gross National Product of the country is only 0.3%. Population of Pakistan is growing at a rate of 2.6% per annum resulting in declining in the per capita forest area. Expansion in the area of public forests is not possible; however there is a vast scope of growing trees on agricultural land which can contribute substantially to the ever increasing demand of wood production (Pakistan National Forest Policy, 2010).

Trees outside forests

As mentioned earlier, more than 90% of the fuel wood requirements of the country are met by trees outside forests (Table 3). The need of promoting tree plantations on agricultural land been recognized for a long time to fulfill the ever increasing demand of fuel and fodder. Since the very beginning of the creation of the country, tree planting has been encouraged by providing the saplings of multipurpose tree species free of charge to the general public. The 1955 forest policy recommended block plantations by farmers’ cooperatives through their education and extension. The 1962 policy also recommended the creation of the institution of farm forestry under Agriculture Department to supply saplings of multipurpose tree species to the general public at a nominal rate. Under this policy, pilot projects on farms were initiated to encourage farm forestry and research on shelterbelts and windbreaks. Later on during 1984-94, under the USAID-funded Forestry Planning and Development Project and a number of development projects were undertaken to support the establishment of woodlots

on degraded farmlands, waterlogged and saline soils and denuded upland watersheds. Influenced by the success of the USAID project, the 1991 policy emphasized the promotion of afforestation on marginal farmlands, supplying seedlings at nominal cost and through an effective outreach/extension program. There is a need to develop cost-effective methods to conduct an inventory of trees outside forests.

Table 3. Estimated growing stocks on private farmlands

Province	Area of farms (ha)	Growing stock on private farmland			Reported removals from private farmlands			
		Millions of m ³			Millions of m ³			
Azad Kashmir	171 523	1.23	0.83	2.06	0.00	0.02	0.02	0.9
Balochistan	1 575 898	1.97	1.46	3.43	0.01	0.00	0.01	0.3
NWFP	1 658 680	3.70	4.86	8.56	0.07	0.00	0.07	0.8
Punjab	12 099 508	22.14	23.96	46.10	1.57	0.16	1.73	3.8
Sindh	3 725 884	4.95	3.58	8.53	0.72	0.03	0.74	8.7
Gilgit Baltistan	500 000	4.16	3.80	7.96	0.00	0.02	0.02	0.3
Total	19 730 493	38.15	38.49	76.64	2.37	0.23	2.60	3.4

Source: FSMP farm forestry survey.

Agroforestry can be defined as a deliberate integration of woody components with agricultural and pastoral systems on the same piece of land either in a spatial or temporal sequence in such a way that both ecological and economical interaction occurs between them (Kalinganire et al., 2008). Agroforestry has been practiced traditionally in Pakistan since times immemorial to harvest multiple benefits from the same piece of land. According to a survey conducted by Punjab Economic Research Institute (PERI, 1999), the number of trees per acre in the province of Punjab was 17 and the trend was on the increase. According to an estimate, 90% of fuel wood requirements and 55% timber requirements are being met from the trees grown on the farmland. However, the potential of harvesting agroforestry benefits are immense (Sheikh et al., 2000).

Trees on agricultural land are very important asset which supply economic returns to the farmer in case of crop failure or supplement their income. They also trap and/or recycle nutrients in the soil. Leguminous trees provide nitrogenous fertilizer by fixing atmospheric nitrogen and also provide nitrogenous fertilizer through incorporation of leaf litter into the soil (Sangha et al., 2005). Another important advantage of growing trees on agricultural land is supplementing farm

economy without much of additional efforts and expenses (Khan 1989). Farmland planting of trees is like fixed deposit available in the rainy days or at the time of need or failure of crops due to natural calamities. Often, the unexpected expenditures such as weddings, funeral or during economic recessions can be met from the return of farmland trees (Pakistan National Conservation Strategy, 1990).

Trees on farmland improve the microclimate and it is not uncommon to feel the cooling effect of the trees on a hot summer day. Trees thus protect us, our animals and houses from blazing sun in summer and cold winds in winter (Simons and Leakey, 2004). The limits of production from particular soils are conditioned by quality and management practices. Thus the activities which are basic for the promotion of the optimum land use are: land resources inventories, assessment of degradation hazards, evaluation of production capacity, improvement of soil fertility, land reclamation combating desertification and integrated land use planning (Baig et al., 2008). The potential contribution of trees to soil improvement is one of the major assets of agroforestry in general (Sanchez et al., 1997). The enhancement of soil fertility by trees is conspicuous in studies which compare productivity of crops grown on soils formed under tree canopies and on control soils in open sites (Craig and Wilkinson, 2004). Differences in soil fertility as demonstrated by in situ crop productivity differ at varying distances from the tree (Botha, 2006). Generally, higher soil nutrient status under tree cover is reflected in the mineral content of under story herbaceous species (Tonye et al., 1997). Soil infertility is the result of the pressure on the land due to a continuous cycle of crop growing without allowing it to rest. It, therefore, should be realized that in order to ensure optimum land use, it is important that a country's land resources should be assessed in terms of suitability at different levels of inputs for different types of land use such as agriculture, grazing and forestry. In many developed and developing countries, this integrated land use has been given the names of agroforestry, agrosilvopastoral activity etc. where trees are being grown in conjunction with agricultural crop and where large herds of livestock are being raised under agrosilvopastoral system of land use (Gebrehiwot, 2004). It has been suggested that if a large amount of genetic diversity is removed from the system, a complete replacement of taxa would require a long period of time. Migration in the basin was remarkably rapid and a return to diversity levels took less than 5 million years. Regionally restricted environmental changes can also account for different recovery rates in different regions. Monsoonal climatic conditions favored a more rapid recovery in South Asia (Jablonski, 2002). The primary processes held responsible for the formation of high fertility around trees relate to enhanced biological processes associated with the seasonal and long term return of nutrients accumulated in trees to the soil through litter fall, root decay and exudation, and their mineralization, as well as leaching of nutrients stored in

canopies. Soil texture sometimes differs according to tree size. Reasons behind these variations related to tree size are not clearly understood (Sangha et al., 2005). Increases in organic matter and improved microclimatic conditions trees enhance soil microbial and enzymatic activity, decomposition and physical characteristics (Tian et al., 2001). When this is compared to open sites, biological activity is two to three times higher. Fine soil lost through wind erosion may be intercepted by trees and deposited through fall and stem flow. Trees also increase soil nitrogen availability due to Nitrogen fixation (N'goran et al., 2002). Increased fertility under trees may also be due to bird droppings and this is integrated in livestock, dung deposition by animals which rest and feed under tree shade. The tree effect may be more pronounced where livestock is excluded than in natural agrosilvopastoral systems (Anon, 2000). Small trees induce little fertility change in their soil environment and produce significantly less organic litter and root turnover inputs.

Agriculture and climate change

Agriculture is both directly and indirectly affected by the climate change, by change in soil water relations, shift in carbon and nitrogen cycles, directly influencing crop growth and development and increased incidence of weeds, pests and diseases. These effects are further exacerbated by means of increased heat stress, increased evapotranspiration, shortened growing seasons, increased photosynthetic activity and reduced water use due efficiency due to increased carbon dioxide in the atmosphere. Impacts of climate change on agriculture has been assessed and is generally agreed that the following major challenges will be faced by the agricultural systems as a result of climate change (Reilly et al., 2001; Das, 2003).

1. Due to an increase in average annual temperature in the northern parts of the country, cropping area may extend/shift towards north.
2. Water requirement of crops will likely to increase as a result of higher evapotranspiration demands.
3. Reduction in the amount of plant available water in most places.
4. Extreme events of floods and cyclones may result in increased degradation of land resources due to accelerated soil erosion.
5. Incidence of weeds, new pests and diseases will likely to increase.
6. Cost of input may rise due to increase in energy and other input costs.
7. More land will be required for future needs of biofuel production resulting in increased food prices which may have adverse impact on accessibility of food to the poor.
8. Genetic erosion may lead to decrease in biodiversity resulting in extinction of some vulnerable species.

Pakistan is rated among the top 10 most vulnerable countries to climate change as per independent international assessments such as that by German Watch, an NGO based in Germany. Listed below are the major climate change related concerns of Pakistan and some recent examples of its vulnerability to climate change related extreme events:

Major Concerns

- Increased variability of monsoon pattern which may be delayed
- Retreat of Hindu Kush Himalayan glaciers affecting Indus River System Flows
- Increased occurrence of extreme events of floods, droughts, cyclones, extreme high / low temperatures cloud burst etc.
- Arid and semi-arid regions of the country will undergo severe water and heat stress which may lead to reduced agricultural productivity
- Increase in deforestation/ degradation of forests and threat to biodiversity
- Penetration of brackish water into the Indus delta as a result of rise in sea level rise resulting in great risk to mangrove forests and breeding grounds some species of fish
- Health hazard to human beings and livestock

Examples of Pakistan's Vulnerability

- Increase in extreme events over the past two decades
- Devastating floods of 2010 and 2011 (about 2000 deaths, 20 million people homeless, 10 billion dollar damages in 2010 alone);
- Flooding during 1992, 1997, 2003, 2006, 2012, 2013 and 2014;
- Cloud burst rains of Lahore (1996), Islamabad (2001) and Karachi (2009)
- Worst drought events during 1999 - 2002; Droughts in Thar area of Sindh and Cholistan area of southern Punjab in 2014;
- Intense heat waves during 2003, 2005, 2007 and 2010 rise in temperature up to 53.7 °C
- Severe cyclones of 1999, 2007 and 2010.

Climate change has emerged as the greatest environmental problems which modern world is facing today. Emission of greenhouse gases, enhanced concentrations of atmospheric gasses like carbon dioxide, methane and nitrous oxide are contributing to the changes of global climate. Climate change may result in rise of sea level, changes in rainfall pattern and shifting of climatic regions due to increase in temperatures. Incidences and intensities of droughts,

storms and flood are expected to increase owing to change in climatic patterns. Global temperature can increase by 1.8°C to 4°C with an average increase of 2.8°C of temperature (IPCC, 2007). Human beings are mainly responsible extra generation of carbon dioxide due to deforestation/degradation of forests and massive use of fossil fuels during industrialization era. During the modern industrialization, the carbon dioxide concentration has increased from 280 ppm to 380 ppm (Stern, 2006). Agriculture is directly under threat as it is highly dependent on climatic conditions. Changing climate has directly threatened the productivity of agriculture and it has become vulnerable to both economical and physical aspects of climate change. Agricultural productivity is likely to be affected by a number of climate change parameters which include shift in rainfall pattern, rise in temperature, change in sowing and harvesting time, decreased water availability and land degradation. Effect of climate change may not be very huge; however, the regional effects in some parts of the world might be more extensive. Some regions for example parts of northern hemisphere will benefit from climate change while other regions will be negatively affected. Not only the overall production from agricultural commodities will be affected as a result of climate change but this will also affect the economic growth by affecting the supply and demand of many agricultural commodities, profitability of the farmers and trade and prices of these commodities (Kaiser and Drennen, 1993). Increasing levels of greenhouse gases will likely to affect the agriculture sector of developing countries as compared to the developed ones (Kurukulasuriya et al., 2006; Seo and Mendelsohn, 2008). Developing countries are more at risk at the hands of climate change as these countries mostly rely on labor intensive agriculture, on the other hand, developed countries have the ability to cope with the climate change as they have the technologies available for and better adoption/ adjustment (Mendelsohn et al., 2001).

In the Asian perspective, continuous rise in the global temperature has been already been observed across the region. The temperature increase in this part of the world has already been observed. The relatively cooler regions are becoming warmer. Incidence of precipitation in Asia is increasing it wetter. Heavy rainfalls are likely to occur during wet seasons hence, the chances of flood will increase. On other hand, dry season will get drier making conditions of extreme drought. This scenario is threatening the agricultural productivity and decreasing income growth of farmers and countries (ADB, 2009). Climate change is posing serious threats to farmers of Asia especially those living in the marginal areas such as mountains, dry lands and deserts areas that are deficient in natural resources. Temperatures rises are expected in the arid areas of northern Pakistan and India and Western China. An estimated number of 500 million rural poor live in the Asia and a majority of them are subsistent farmers living in the rain-fed land ecologies. During the past few decades, production of major cereal crops like rice,

maize and wheat has decreased due to water stress mainly as a result from temperature increase (UNFCCC, 2007). Impacts of climate change are even more alarming in South Asia and agricultural productivity may be reduced up to 50 percent reduction in wheat only by the year 2050 (MoE, 2009).

Agriculture of Pakistan is more at stake by the effects of climate change. As mentioned earlier, Pakistan is basically an agriculture country employing 47 percent of people and contributing 21 percent to the GDP. Due to the climate change, temperatures are in general on the rise and rainfall is unpredictable. Temperature is expected to rise by 3 degrees by 2040 and up to 5-6 degrees by the end of the 21st century. The agriculture sector is economically more vulnerable as a result of climate change. Pakistan is at 28th place among the countries which are most vulnerable by climate change. Since 22 out of 28 countries are situated in Africa, hence Pakistan is included in the top ten countries outside Africa (MoE, 2009). World Bank has enlisted Pakistan among the 12 highly exposed countries to climate change. Rise in temperature, intense rains including cloud bursts, frequent droughts and decrease in agricultural productivity are expected in Pakistan due to climate change. Pakistan is paying the price of climate change without being aware of it. Rains are likely to intensify in the northern areas of Pakistan (IPCC, 2007). Previous studies have also indicated that the drier lands will greatly be affected due to climate change (Eid et al., 2007, Kurukulasuriya and Mendelsohn, 2008). Substantial losses have been observed in crop yields hence, reducing the income of the dry land farmers.

Role of Agroforestry in adapting to climate change

Agroforestry has the potential to adapt to the challenges of climate change. One of the important practices can be the growing of fast-growing, nitrogen fixing trees and shrubs in agricultural fields. This will not only improve the soil fertility but will also arrest the soil erosion. In an integrated farming system, the overall production from trees, crops and livestock can be much higher than those from sole systems due to efficient use of resources especially nutrients and soil moisture. Trees in the agricultural fields improve soil fertility, control soil erosion, maintain soil organic matter, improve soil physical properties, increase soil nitrogen, extract nutrients from deeper layers of the soil and promote nutrient cycling. In this way, agroforestry systems the most valuable adaptation measures in making communities resilient to the impacts of climate change and do discuss the same in relation to the challenges posed by the changing and variable climate (Rao et al., 2007).

Adoption of agroforestry systems

Apart from meeting the vital requirements of food and income, Agroforestry systems have profound environmental benefits. If practiced with care, tree and

crop species selected can meet farmer's needs for food and cash. If properly managed, they can reduce the competition for water, nutrients and light between the crop and tree component is separated over time and space (Sanchez 1995). Through agroforestry systems the resources are utilized in such a way that maximum returns from soil, water, nutrient, and solar energy can be achieved in economically, environmental friendly and sustainable way. However, the environmental benefits from agroforestry systems far exceed the economic returns. During the recent past, environmental services such as carbon sequestration, watershed protection and biodiversity conservation have become a top priority and these are being financed by the international agencies. It has been estimated that the carbon payments are sufficient to help to smallholder agroforestry farmers increase production.

Soil and water conservation through provision of permanent cover

It has been proved beyond a shadow of doubt that climate change plays a role in land degradation. Rise in temperature, coupled with low moisture availability may lead to decrease in organic matter of the soil resulting in poor soil structure, reducing infiltration of rain water and increasing runoff and soil erosion (Rao et al., 1998). In case of increase in the occurrence of extreme and unexpected rainfall events will adversely affect the magnitude of soil erosion (WMO, 2005). Halting the land degradation and improving the physical, chemical and biological properties of soils is necessary to achieve the optimum yields from any agricultural system. Agroforestry system is in the most efficient in bringing positive changes in all these conditions. Agroforestry systems involving contour hedgerows and presence of trees and shrubs can play a very important role in halting and even reversing land degradation because they provide permanent soil cover, increase organic carbon, improve soil structure by increasing organic matter, increase infiltration of water and also increase soil fertility (Rao et al., 2007).

Moderating microclimate

Agroforestry systems having some good numbers of trees provide shade and can reduce the scorching heat stress and produce positive change in the microclimatic conditions locally by stopping penetration of solar radiation, reduce wind speed, reduce evapotranspiration, and improve soil water use (Monteith et al., 1991). Beneficial aspects of changes in microclimate include but are not limited to protection of heat sensitive crops like, ginger, turmeric and cardamom from heat stress. In agro-agroforestry systems, trees act as wind breaks and shelter belts and slow the wind speed hence reducing evaporation and physical injury to crops. They also act as mulches and reduce soil temperature and soil erosion thus maximizing resource use efficiency. Temperature difference of 4 to 5°C between

open and shade for various plantations has been observed for various agroforestry systems has been recorded (Beer et al. 1998; Steffan-Dewenter et al. 2007). Shelterbelts and windbreaks (parallel rows across the wind direction) is also an option widely used to reduce the speed of wind thus controlling wind erosion and evapo-transpiration. If shelterbelts are designed properly, their effect extends from 10 to 25 times the height of trees on to the leeward side.

Factors affecting the performance of agroforestry systems depend upon the compatibility of crop and tree type, number and distribution of trees, height and species of the tree, tree crop management and weather during the entire growing season. Studies have revealed that fodder crops alfalfa, clover have shown the best results while cereal crops like maize, and wheat have been less responsive (Brenner 1996). The negative effect of shade effect has been reported more in case of C4 plants (Ong, 1996).

Agroforestry systems for sustainable diversification of agricultural systems

Agroforestry systems provide diversification which helps in increasing the farm income and/or reducing income fluctuations by enhancing the income-generating activities because multiple production activities complement the economic dimensions including crops, trees and livestock together (Dixon et al., 2001). Thus integrated agroforestry systems are a suitable means for improvement of sustainability through of agricultural systems. A fast growing tree species of poplar has proved a major tree component on many farms in Peshawar, Charsadda and Mardan districts of Khyber Pakhtunkhwa province of Pakistan (Chaudhry, et al., 2003) and turmeric cultivation in Changa Manga plantation in the Punjab province (Ashraf and Javed, 2005). Hence, Agroforestry systems besides providing the subsistence requirements of the farmers also play a vital role generating extra cash (Mendez et al., 2001).

Sources of extra income from agroforestry interventions include plantations for fuelwood production, for charcoal industry and small-scale nursery enterprises. Farmers associations can be quite helpful which can develop links with research and extensions and keep an eye on the market (Russell and Franzel, 2004).

Enhancing the use efficiency of rain water

Climate change is likely to have adverse effect on availability of water both through direct and indirect way. The direct impacts include changes in rainfall patterns while the indirect include increase in losses through runoff and evapo-transpiration as a result of rise in temperature. There are several ways and means with which water efficiency in agroforestry systems is far better as compared to annual crops. For example land under annual crops lies bare for extended periods of time, whereas under agroforestry systems having trees and shrubs can utilize

the water in the soil after crop harvest and the rainfall received outside the crop more efficiently. Secondly, agro forests increase the productivity of rain water by capturing a larger proportion of the annual rainfall by reducing the runoff and by using the water stored in deep layers. Thirdly, the changes in microclimate (lower air temperature, wind speed and saturation deficit of crops) reduce the evaporative demand and make more water available for transpiration.

Despite its importance, the knowledge and understanding of the competition for resources between the tree and crop components remains imperfect due to the complex nature of the interactions and difficulties associated with quantification. Much of the evidence is based on the interpretation of the observations made on above ground components of the system which have mostly reported negative effects of trees on crop yields.

Improvement of soil fertility

There are many ways by which trees can contribute in improving the nutrient supply, for example increasing the nutrient input to the soil, enhancing nutrient recycling, decreasing nutrient losses from the soil while providing extra environmental benefits. Incorporation of the nitrogen-fixing leguminous trees like *Sesbania*, *Tephrosia*, *Crotalaria*, *Glyricidia*, and *Cajanus*, if intercropped in maize can accumulate 100 to 200 kg N ha⁻¹ within 2 years in sub humid tropical regions of East and Southern Africa. These amounts of nitrogen thus fixed from atmosphere are almost equal to those applied as fertilizers by farmers to the maize crop. (Sanchez, 2002).

Reducing carbon emissions and sequestering carbon

Agroforestry system has a great role to play in the context of climate change by mitigating the carbon dioxide emissions and sequestering carbon from the atmosphere. The tree component of the agroforestry systems is a great sink for atmospheric carbon on agricultural land. There are three major pathways through which tree can help in reducing atmospheric carbon: firstly by conserving the existing carbon pools through deforestation and degradation of forests, secondly carbon sequestration integration of farms with trees by improving fallows and thirdly substitution with alternate energy as a replacement fossil fuel use (Montagnini and Nair, 2004)

Agroforestry systems in the country and their classification

Agroforestry has been included in the traditional landuse by the subsistence farming community all over the world. In Pakistan, farmers have been growing trees in association with the field crops, vegetables and other horticultural crops to meet their domestic needs (Amin, 1981). The objectives of the agroforestry

systems are to maximize the positive interaction of the resources to harvest a higher and sustained productivity, thus improving the livelihood. Agroforestry systems include but are not limited to subsistence livestock silvo-pastoral systems, home gardens, timber production at farm level, trees integrated with crops and biomass plantations. Agroforestry systems are found in a wide diversity of biophysical conditions and socio-ecological characteristics. The term Agroforestry systems is also used to include the role of trees in landscape level interactions, such as nutrient flows from forest to farm, or community reliance on fuel, timber, or biomass available within the agricultural landscape etc. (Zomer et al., 2009). Mixed farming systems have been a traditional way of life for farmers of Pakistan. In every village there are various combinations of tree, crop and animal-husbandry activities according to the local requirements. An outline of different agroforestry systems and practices are prevalent in various ecologies of Pakistan is given below (Table 4).

Table -4. Important Agroforestry Systems and Practices in Pakistan.

Agroforestry Practices	Brief description (of arrangement of components)
A. <u>AGRISILVICULTURAL SYSTEMS (crop including tree crops, and trees)</u>	
1. Improved fallow	Woody species planted and left to grow during the fallow phase.
2. Taungya	Combined stand of woody and crop species during early stages of establishment of plantations
3. Multipurpose trees on crop land	Trees scattered haphazardly or according to some systematic patterns on bunds, terraces or plot/field boundaries
4. Tree gardens	i. Mixture of fruit trees, fuelwood/fodder spp. In alternate or other regular arrangement. ii. Integrated multistory (mixed, dense) mixture of fruit trees; fuelwood/fodder spp. iii. Intercropping with agric. crops.
5. Home gardens	Intimate, multistory combination of various trees and crops around homesteads.
6. Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers, etc. with or without grass strips, trees for soil reclamation.
7. Shelterbelts & windbreaks, live hedges.	Trees around farmlands/plots.
8. Agroforestry for Fuelwood production	Interplanting firewood species on or around agri. Lands.

B. SILVOPASTORAL SYSTEMS (TREES + PASTURE AND OR ANIMALS)

- | | |
|---|--|
| 9. Trees on rangeland or pasture | Trees scattered irregularly or arranged according to some systematic pattern |
| 10. Protein banks | Protection of protein rich tree fodder on farm/rangelands for cut-and carry fodder production. |
| 11. Forests plantations with pastures and animals | Cattle in forest plantations and other forests |
| 12. Living fences of fodder trees and shrubs | Woody hedges for browse |

C. AGROSILVOPASTORAL SYSTEM (TREES + CROPS + PASTURE/ANIMALS)

- | | |
|------------------------------------|--|
| 13. Home gardens involving animals | Intimate, multistory combination of various trees and crops, and animals, around homesteads. |
| 14. Multipurpose woody hedge rows | Woody hedges for browse, mulch, green manure, soil conservation, etc. |

D. OTHERS

- | | |
|---------------------------|--|
| 15. Apiculture with trees | Trees for honey production |
| 16. Aquaforestry | Trees lining fish fish ponds, trees leaves being used as forage for fish. |
| 17. Multipurpose woodlots | For various purposes, (wood, fodder, soil protection, soil reclamation, etc.). |
-

Some typical agroforestry systems and practices various parts of the country are given below:

- i. **Tree planting campaign in the Thal Desert:** Tree planting in the desert of Thal started in early fifties with the availability of water is an example as to how the trees were used in conjunction with agricultural to the advantage of both. Tree planting was done in the form of (a) compact blocks of forests to be known as national parks at that time, (b) An area of 40 ha village forests in every settlement blocks of 400 ha was recommended and (c) establishment of shelterbelts of trees along water channels and road and other infrastructure. In the farm of 40 ha, foundation of village woodlot system of forests was surely laid. The shelterbelts were necessary to safeguard the roads, water channels, agricultural fields, fruit orchards from the ravages of drifting sand dunes and scorching sun. Employment opportunities were generated in the far flung desert areas. As a result, cottage industry was developed in the area and economic uplift of the rural poor started.
- ii. **Poplar on farmlands in Peshawar Valley:** The farmers of Peshawar, Charsadda and Mardan districts have been growing poplar as a cash crop since

as early as seventies. Planting has been done around agricultural fields, along water courses, in block plantations and in inter-culture with agricultural crops and fruit plants. The farmers who used to grow *Populus nigra* were motivated with the interdiction of hybrid poplar due to fast rate of growth of the tree which attained about 15 cm diameter and a height of 10 m in 6 years. The wood had a ready market for several uses such as production of safety matches, shuttering, scaffolding, packing cases, chipboards, etc. The poplar wood grown in the Peshawar valley is the major price source of raw-material for the match industry. The wood supplied to the units has generally a moisture content of 50-70%. About 20-30% round wood is wasted during veneering process which includes bark, trimmings and cores. In addition to wood, other material such as paper, cardboard, glue and chemicals are also used to produce matches. The match industry currently employs more than 3000 persons throughout the country. The industry is presently getting sufficient wood as raw material.

Hybrid and non-hybrid poplars have been also been planted in association with the agricultural crops in Peshawar, Charsadda and Mardan Valley. Saplings are planting with plant to plant and row to row distance of 5 m to allow the tractors and other agricultural implements to move about freely. Under this geometry, the total numbers of trees planted are 330 per ha. With a margin of about 10% failures during the whole rotation period of 10 years, 300 trees are left for felling. After 10 years, these trees are ready for harvesting. The land also remains under crop cultivation for the first three years after which the crowns of the tree meet and penetration of light becomes difficult.

- iii. **Fruit and Forest Trees in Swat Valley:** In the Swat valley of Pakistan, agrisilviculture (growing of trees with crops) and silvopastoral (growing of trees on pastures) are the major agroforestry systems traditionally practiced. The most frequent method of growing trees (except fruit trees) on the farms in the study area is through deliberate retention and management of naturally regenerating tree seedlings. List of major fruit trees growing in the agroforestry system of Swat valley is given in Table 5.

Table 5. Distribution / abundance of fruit trees in Swat (decreasing order)

S.No.	English name	Scientific name
Winter fruits		
1.	Pear	<i>Pyrus sp.</i>
2.	Apple	<i>Eriobotrya japonica</i>
3.	Mulberry	<i>Malus domestica</i>
4.	Loquat	<i>Morus spp.</i>
5.	Citrus	<i>Citrus spp.</i>
Summer fruits		
6.	Persimmon	<i>Diospyrus spp.</i>
7.	Peach	<i>Prunus persica</i>
8.	Walnut	<i>Juglans regia</i>
9.	Plum	<i>Prunus communus</i>
10.	Apricot	<i>Prunus armeniaca</i>
11.	Watermellon	<i>Citrus lanatus</i>
12.	Almond	<i>Prunus dulcis</i>

Source: Irshad, et al., 2011

A list of forest and fruit trees being grown in the Swat valley is given in Table 6.

Table 6. Distribution/ abundance of farm trees in Swat (decreasing order).

S.No.	English name	Scientific name
1.	Poplar	<i>Populus nigra</i>
2.	Persimmon	<i>Diospyrus kaki</i>
3.	Black persimmon	<i>Diospyrus lotus</i>
4.	Peach	<i>Prunus persica</i>
5.	Chinese pear	<i>Pyrus sinensis</i>
6.	Walnut	<i>Juglans regia</i>
7.	Apple	<i>Malus pumila</i>
8.	Acacia	<i>Robinia pseudoacacia</i>
9.	Alnus	<i>Ulnus nitida</i>
10.	Willow	<i>Salix babylonica /Salix tetrasperma</i>
11.	Plum	<i>Prunus communes</i>
12.	Apricot	<i>Prunus armaniaca</i>
13.	Fig	<i>Ficus plamate</i>

S.No.	English name	Scientific name
14.	Pinus	<i>Pinus wallichiana</i>
15.	Cedar	<i>Melia azadarich</i>
16.	Mulberry	<i>Morus nigra</i>
17.	Bluejack oak	<i>Quercus incana</i>
18.	Olea	<i>Olea ferruginea</i>
19.	Oriental plane	<i>Platenus orientalis</i>
20.	Pear	<i>Prunus communis</i>
21.	Apricot	<i>Prunus armeniaca</i>
22.	Loquat	<i>Morus spp.</i>

Source: Irshad, et al., 2011

- iv. **Eucalyptus camaldulensis shelterbelts and agricultural crops in Sindh:** In Mirpur Khas, Sind province, Eucalyptus camaldulensis was planted in early eighties in form of shelterbelts. For this purpose 3 rows in each belt, saplings were planted 2 m apart in rows with plant to plant distance of 1 m in each row. These shelterbelts were 6000 m long and 180 m wide. The trees attained an average height of 13 m and a diameter of and a diameter of 15 cm after six years. It was revealed that in the sheltered areas within 10-15 m distance from the shelterbelt, due to the competition for water and nutrient on either side of the belt, there was competition being comparatively milder on the posts falling on western and south-western side of the belt. However, beyond the 15 m distance the shelterbelt had a positive effect on the yield.
- v. **Acacia nilotica block plantation (Hurries) in Sindh:** The practices of raising tree alongside crops on the marginal lands and agricultural lands by the farmers has been in practice in the Sindh province since late fifties when government offered 4 ha of land free of cost to any farming family willing to raise Acacia nilotica in block form to meet the fuelwood demand for increasing population and also development of the marginal land for profitable agriculture. This was the first willful raising tree crops by the government otherwise; the farmers had already been traditionally raising trees on their farmlands more than century ago as community forestry. Farmers are still growing “Hurries”, because from farmer’s perspective, raising hurries is certainly an economic production. Study conducted in this regard showed that farmers were getting handsome profit from the sale of hurries and cost-benefit ratio was 1:1.72 (Baig and Ehrenreich, 1993).

Hurries, later on, became an integral part of land development due to several incentives by the government including availability of free land, no water tax

- and waiving land revenue. The farmers immediately got motivated due to; lower water requirements of the trees which could otherwise be spared for agriculture crops; the resultant increase in overall productivity due to atmospheric nitrogen fixing ability of the trees; and as an insurance against emergencies for ready cash. It was reported at the end of that time that the tree crop yield from the agricultural land was greater than the average yield from the land where no crops were planted. The report concluded that the trees benefitted from the additional irrigation, land cultivation and fertilization. The trees did not depress the agricultural crop yields (Keerio, 1997).
- vi. **Simal (Bombax ceiba) and cotton:** Several cotton growers in Sahiwal, Toba Tek Singh and Multan districts of Punjab have grown Simal on the water courses and also in between the rows cotton and other crops are grown. Farmers are selling 10-years old trees to the industry to earn extra income (Anjum et al., 2011).
 - vii. **Shisham (Dalbergia sissoo) on farmlands:** Shisham is another multipurpose tree extensively planted by farmers on the borders of the fields. It is certainly slow growing and after 20 years, one tree would give about 0.5 m³ of timber. However, wood is quite valuable and is used in manufacture of high quality furniture. Along the canals where land has been brought under cultivation due to availability of water, farmers have planted Shisham very extensively. Interviews conducted with the farmers have indicated that they have removed all their investment for land including cost and development charges merely by selling the Shisham trees they planted on the field borders and along water course. Survey has revealed that farmers of the Punjab province prefer Shisham over other trees because of economics (Table 7).

Table 7. Tree species preferences given by farmers to promote agro forestry on their farmlands.

Tree Species	Frequency	Percentage
<i>Dalbergia sisso</i>	87	69.6
<i>Acacia nilotica</i>	68	54.4
<i>Populous deltoids</i>	47	37.6
<i>Eucalyptus camaldulensis</i>	36	28.8
Fruit trees	27	21.6
<i>Melia azaderach</i>	26	20.8

Source: Rahim and Husnain, 2010

A survey of farm plantations in various districts of Punjab has revealed that there are more than 250 plantations. Districts of Attock, Lahore, Pakpattan, Khanewal and Rahim Yar Khan have twenty or more plantations while Kasur, Okara, Dera Ghazi and Bahawalpur have five or less plantations (Table 8).

Table 8. Survey of farm plantations in various districts of Punjab

No.	District	Farm plantations
1.	Attock	26
2.	Chakwal	10
3.	Jhang	10
4.	Toba Take Singh	12
5.	Faisalabad	12
6.	Sheikupura	19
7.	Lahore	20
8.	Gujranwala	10
9.	Hafizabad	10
10.	Kasur	5
11.	Okara	4
12.	Sahiwal	6
13.	Pakpatton	25
14.	Khaniwal	21
15.	Multan	11
16.	Vehari	13
17.	Muzaffarghar	13
18.	Dera Gazi Khan	4
19.	Bahawalpur	5
20.	Rahim Yar Khan	21
Total		257

Source: Rahim and Husnain, 2010

- viii. **Turmeric and poplars:** In the Changa Manga irrigated plantation in the Punjab province of Pakistan, land after planting with poplars at a row to row and plant to plant distance 5 m, is leased to the local farmers for cultivation of turmeric in between the lines for a period of two to three years. This activity has been highly beneficial to the local farmers who became very prosperous. However, cultivation of turmeric is labour-intensive and the whole family is involved in digging out and collection of rhizomes and their drying and storage.
- ix. **Mulberry for silk production and basket making:** When mulberry trees are planted, these are beneficial in more than one way. Not only the tree gives reasonably good fuel, fodder and excellent timber for sports goods industry but also it has the inherent blessing of providing food material for silk worms. Rearing of silk worm is a highly remunerative cottage industry. Grafted varieties of mulberry yield nutritious fruit which is a delicacy in cities.
- x. ***Tamarix aphylla* shelterbelts in Thal:** During eighties, a project on introduction of shelterbelts in the Thal desert was initiated by the Rangeland Research Institute, Pakistan Agricultural Research Council for large-scale land reclamation and rehabilitation of the hot and arid Thal desert from wind erosion. Community was mobilized and Frash (*Tamarix aphylla*) cuttings were distributed among the farmers to plant them against the direction of wind. This activity project was very successful and this project won the United Environment Programme Award for Desertification Control for the year 1995.
- xi. **Block plantations of Ipil Ipil on private lands:** Due to the fast growing quality and diverse uses of Ipil Ipil, farmers of different areas of Pakistan have started planting Ipil Ipil as block plantation with the aim to improve soil physical properties and ability to fix atmospheric nitrogen. The saplings planted at different spacing of 0.5 x 0.5 m, 0.75 m and 1 x 1 m. Maximum yield of 25 ton per ha was obtained from relatively closer spacing, 19 ton per ha from the middle spacing, and about 13 ton per ha from 1 x 1 m spacing. The tree coppices readily and in the 2nd year, it gave even higher yields. The wood is used for fuel and leaves as livestock feed.
- xii. **Agroforestry in Balochistan:** Eucalyptus spp. was planted in Mastung area of the Balochistan province on the borders of agricultural fields to act as windbreak to protect the crops from the desiccating wind and physical injury from the sand storms. This effect of wind can be eliminated or reduced by shelterbelts and windbreaks. It has been established that planting of shelter belts and windbreaks enhances agricultural productivity in these areas (Jafri et al., 1991 and Mohammad and Ehrenreich, 1993). In a sandy parts of the

Mustung valley of Balochistan province, wheat yield increased up to 14% with three rows of shelterbelts of *Tamarix gallica*, *Arundo donax* and *Calligonum polygonoides*. This study also revealed that soil moisture in the upper layers in soils protected by the shelterbelts was almost 26% higher than without shelterbelts.

Association and interaction

- i. Above ground interactions:** Above ground interactions in agroforestry systems such as changes in the intensity of light, temperature, and relative humidity may have positive or negative effects on understory crops. However, analysis reveals that atmospheric interactions in agroforestry systems in the arid and semi-arid regions have little importance as compared to below ground interactions (Ong and Leaky, 1999).
- ii. Belowground Interaction:** Agroforestry systems are more advantageous over annual sequential cropping systems because they maintain of soil fertility. These systems provide a favorable environment for biological activity of the soil enhancing litter decomposition and improving the soil structure, thus cycling the nutrients more efficiently. Fundamentally, in agroforestry systems plant species with different life forms such as trees/shrubs and annual crops or grasses occupy different soil strata with their root systems when grown together, complement each other in absorbing water and nutrients (Schroth, 1999). Therefore, the vertical distribution of roots is of particular interest in the agroforestry systems. Rooting depth of different floral components determine the optimum subsoil resource utilization which makes them less dependent from the supply in the topsoil which may be made available to annual crop with relatively shallower root systems utilizing resources from upper layers of the soil (Emerman and Dawson, 1996).

There are a number of ways and means through which soil fertility can be maintained and/or improved under agroforestry systems. Atmospheric nitrogen fixing legumes improve the N status of the soil, and also improve nitrogen nutrition and yields of associated crops on under nitrogen deficit conditions of low application of nitrogenous fertilizer. The reduction of nutrient leaching and recycling of subsoil nutrients by deep-rooting trees can improve the availability of nutrients in the system and reduce negative environmental impacts (Vohland and Schroth, 1999).

- iii. Allelopathy:** Agroforestry is playing a major role in the sustainable land use and for increasing food production by growing trees and shrubs along with agricultural crops and the same spatial and temporal arrangement. Because these woody and crop species grow side by side, their allelopathic effect compatibility may be crucial to determine the success of an agroforestry

system (Rivzi et al., 1999). Research in the past has revealed that many agroforestry species have negative effects on food and fodder crops. Trees and crop have been grown together in an agroforestry system since times immemorial. In any system the trees and the crops may compete for light, water, and nutrients or have complementary effect on each other. When the interactions between the trees and crops are managed well, agroforestry system, traditional or modern, can perform far better than the sole cropping system. Allopathic effects are generally selective and may vary with different tree or crop species (Melkania, 1986; Stowe, 1979). Mostly allelochemicals are found in leaves; however, the toxic chemicals can also be found in all other parts of the plant and concentration may vary. The allelopathic effects may be so pronounced that for competition for resources in plant communities, many species perform a regulatory role through production and release of chemicals, attractant, stimulate or inhibitor the growth of other plants (Putnam and Tang, 1986). Several plant species have allopathic effects on other crops, e.g. maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.) as reported by Rafiqul-Hoque et al. (2003). As agroforestry systems have both tree and crop components, hence the situation becomes even more complex. In case of legumes allelopathic effect of leachates and extracts of *Pinus roxburghii* in Kumaon Himalaya has been recorded. Mimosine toxicity of *Leucaena Leucocephala* was observed on green gram i.e. inhibitory effect on germination. Various types of trees show different type of positive and negative effect on crops. A possible allopathic effect of Acacia trees has also been recognized. Other authors have shown a large inhibitory potential in the genus of Acacia (Rafiqul-Hoque et al 2003). Auto-toxicity in some annual like corn, *Zea mays* (Marti et al., 1990) and wheat, *Triticum aestivum* (Jessop and Stewar, 1983) has also been recorded. Allelopathic effects in soil and in turn on crops may be altered by changes in soil moisture, soil temperature and other soil factors including fertility (Patrick and Koch, 1958) The effects of secondary substances from allelochemicals may even be long lasting (Patric, 1971) or quite temporary (Kimber, 1973) and can may affect such practices like fertility, stage of the plant and crop rotation. The allelopathic effects are often selective (Melkania, 1983; Stowe, 1979 and vary with the tree species involved because plants will vary in the amounts phytotoxins. Harborne (1977) revealed that trees release some toxins into the soil, which adversely affect the germination and growth of many crops. These are given in Table 9.

Table 9. Allelpathic effect of different tree species on agri-horticultural Crops.

Tree species	Plant part/soil allelochemicals	Affected crop	Effect
<i>Leucaena leucocephala</i>	Mimosine	Green gram, Rice	Inhibitory effect on germination and growth
	Mimosine	Rice, rye lettuce	Inhibitory effect on germination and growth
	Leaf extract	Wheat, maize, pea, mustard	Inhibitory effect on germination
	Soil	Rice	No effect on germination
	Leaf extract	Rice	Inhibitory effect on germination
	Leaf extract	Rice	Stimulatory effect on germination
<i>Acacia tortilis</i>	Leaf, stem and soil extract	Pearl millet, sesame, cluster bean, What	Inhibitory effect on germination
<i>Walnut</i>	Field study	Potato, tomato, Alfalfa	Inhibitory effect on germination
	Field study	Potato, maize, turnip	Inhibitory effect on germination
<i>Bamboo</i>	Leaf extract	Groundnut	Inhibitory effect on growth, chlorophyll and protein content
<i>Eucalyptus citridora</i>	Leaf, stem and root extract	Okra, wheat, cowpea, maize	Inhibitory effect on germination
<i>Eucalyptus tereticornis</i>	Leaf, stem and root extract	Sorghum, cowpea, sunflower	Inhibitory effect on germination and growth
<i>Pinus radiata</i>	Leaf extract	Ryegrass, white clover	Inhibitory effect on rye grass stimulatory effect on white clover
<i>Pinus roxburghii</i>	Leaf and root leachates, decaying litter, field soil	Black gram, green gram, horse gram, soybean	Both inhibitory and stimulatory effect.

Singh et al., 2012

A list of tree species and the allelochemicals, they release is given in Table 10.

Table 10: Tree species with potential allelopathic activities.

Tree species	Allelochemicals
<i>Leucaena Leucocephala</i>	Mimosine
Walnut	Juglone
Azadirachta	Azadirachtin
<i>Eucalyptus sp.</i>	1,4- and 1,8-cineole
Guava	Phenolics
Peach	Amygdalin
<i>Mallus domestica</i>	Phlorizim, Quercetin

Singh et al., 2012

Table 11: Crop species with potential allelopathic activities.

Crop species	Common name
<i>Allium sativum</i>	Garlic
<i>Avena sativa</i>	Oat
<i>Brassica hirta</i>	White mustard
<i>Brassica juncia.</i>	Brown mustard
<i>Cajanus cajan</i>	Pigeon pea
<i>Carthamus tinctorius</i>	Safflower
<i>Cucumis sativus</i>	Cucumber
<i>Glycine max</i>	Soybean
<i>Medicago sativa</i>	Alfalfa
<i>Oryza sativa</i>	Rice
<i>Hordeum sp</i>	Barley

Singh et al., 2012

Allelopathy is not limited to have effect of trees on crops but some trees may have allelopathic effect on other trees. Some tree species are a rich source of the secondary metabolites (allelochemicals), which play a major role in regulating growth patterns of vegetation. These allelochemicals impose environmental stress

on other plants growing in their vicinity. In case of walnut, the toxicity is found to other tree plant like, apple, berry and also grasses and forbs. Auto allelopathy is a main reason of non-establishment of trees causing replant problems. The allelopathic effects of Eucalyptus have been studied extensively (Bajwa and Nazi, 2005; El-Khawas and Shehata, 2005). Phenolic acids and volatile oils released from the leaves, bark and roots of certain Eucalyptus spp. after decomposition have deleterious effects on many other plant species (Sasikumar et al, 2002).

Effect of one crop on another crop or same crop is called “crop allelopathy”. It has been well established that crops cultivated in rotation produce higher yield than those of grown in monoculture. It has been reported that allelopathic effects of alfalfa soil retard the growth of barley, wheat, radish and alfalfa itself.

The allelopathic potential of trees and crop can influence the growth and distribution of associated tree species and the yield of desired plant, and allelopathy has been employed successfully in this context. When the tree and crops grown together they interact with each other either inhibiting or stimulating their growth together they interact with each other either Inhibiting or stimulating their growth or yield through direct or indirect allelopathic interaction. Thus, it plays an important role in an agroforestry system and it is clear that a better understanding of allelopathy can help in developing more sustainable agroforestry system.

Agroforestry technologies (released for general use): At present, there is no system of release of agroforestry technologies, however, many systems including hedgerow intercropping, shelterbelts/windbreaks, home garden, Taungya, growing fruit trees, Fodder banks/protein banks, boundary planting on croplands, establishment of living fences, etc. have proved to be economically viable and are being practiced in various parts of the country.

Agroforestry potential as CSA technology: The FAO defines ‘climate-smart agriculture’ as “agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goals.” (Lipper, 2010). This means that environmental and sustainable methods of farming must be adopted to meet the future needs of agricultural products food, feed, fibre and timber. Climate-smart agricultural practices not only focus on mitigation and adaptation strategies but also provide other benefits. These include: Increased resilience as a result of climate change, reduction in greenhouse gas emissions and improvement in food security.

Although, the natural forest ecosystems are the largest vegetation on earth which provides carbon sink, however, this vast natural resource is under threat due to deforestation and degradation of forests especially in developing countries of the world like Pakistan. It is very difficult to restore these deforested and degraded

sites to their original condition. Hence, there is a need to transform tree based carbon rich ecosystems like plantation forests and agroforestry as carbon sink. Agroforestry systems are spread over one billion ha in different ecosystems all over the world have attained a special significance in this regard.

The trees and shrubs in agroforestry systems have the capacity to store the atmospheric carbon dioxide in plant biomass and soils. Agroforestry systems offer important opportunities of can create synergy between mitigation and adaptation actions with a huge potential in the terrestrial ecosystems in the future. If an additional 630 million ha of unproductive croplands and grasslands is converted into agroforestry system, magnitude carbon sequestration can be enhanced to a great extent. The total above and belowground carbon storage in biomass in agroforestry systems is always higher than croplands. Under various agroforestry systems have increased expectations of carbon sequestration especially in developing countries like Pakistan.

Climate smart agroforestry system of the future will include boundary trees and hedgerows for nutrient recycling, growing nitrogen-fixing trees on farms for enhanced soil nutrient, introducing multipurpose and fruit trees for livelihood improvement, improved fallow with fertilizer shrubs and woodlots for carbon sequestration.

Constraints in up-scaling Agroforestry

The main reason for non-adoption of agroforestry by farmers is lack of awareness. Many farmers are of the view that growing trees on farmland is detrimental to the crops (Nauman et al., 2008). Amir (2003) has also reported that lack of education was the main reason of not adapting the agroforestry and that educating farmers was the only tool to persuade farmers to grow trees in association with crop for better income generation

Farmers are of the view that trees compete with crops for water and nutrients. Many farmers in the Punjab province of Pakistan do not grow trees because of having small land holding and they want to practice intensive for their livelihood. However research has revealed that growing crops under monocultural system, the natural resources are not utilized fully. On the other hand, through agroforestry systems the farmers can utilize soil resources in a better way and get maximum economic returns (Nair, 1996). Some farmers are of the view that marketing of timber and other tree products is difficult as compared to crops (Nauman et al., 2008) and farmers will show more interest to grow trees with their crops if better marketing and economic benefits are ensured. Jamil (2003) also concluded in his study that a majority of the respondents were hesitating to grow trees on their farmlands because they hindered the agricultural crops. Response of different farmers of Faisalabad district of Punjab, Pakistan is given in Table 12.

Table 12. Distribution of respondents with regard to reasons for not planting trees on farmlands

Reasons for not planting trees	Frequency	Percentage
No interest in trees	28	22.4
Not enough land/area to make it viable for tree planting	79	63.2
Land/soil degradation due to trees	22	17.6
Insufficient rainfall	39	31.2
Least economic return from trees	73	58.4
Requires long span for tree growth % associated management problems	33	26.4
No guaranteed markets for wood dispersal	53	42.4
Competition between trees & crops for water and nutrients uptake	86	68.8

Nauman et al., 2008

The farmers generally believe that the trees planted along with agricultural crops damage the crop production and affect the economic returns. Many agronomists are also against including trees in crops because they think that trees retard crop growth through competition and they provide shelter for birds.

Potential for improvement

Agroforestry in particular has a great role to play in the accumulation and mitigation of atmospheric greenhouse gases (IPCC, 2000). Compared to all other types, agroforestry has been considered to have the highest potential for carbon sequestration because the system offers the opportunities of synergies between both mitigation and adaptation. The quantities of carbon present in the above-ground and belowground biomass of an agroforestry system is always far greater than that in an equivalent land-use system without trees and shrubs. It has been estimated that in Southeast Asia, agroforestry systems have the capacity to store 12-228 Mg C ha⁻¹ in humid tropical lands and 68-81 Mg C ha⁻¹ in dry lands (Murthy et al. 2013). An estimate of carbon sequestration from different agroforestry systems is given in Table 13.

Table 13. Estimates of net annual carbon sequestration by agro forestry components.

Agroforestry component	Carbon sequestration (Mg⁻¹.yr⁻¹)
Populus spp.	8
Eucalyptus spp.	6
Bamboo spp.	6.51-8.95
Tropical home gardens	16-36

Source: Singh and Pandey (2011)

Potential for further improvement lies in the fact that agroforestry can provide food security in terms of enhanced food availability, security of land tenure, increased farm income as a result of balanced resource utilization, restoration and maintenance of biodiversity and maintenance of watershed hydrology and soil conservation.

Conclusions

During the past three decades, it has been proved beyond a shadow of doubt that global warming and its impact on the agro-ecosystems is real. Pakistan is included among the top 10 countries which are most vulnerable to climate change. The impact of climate change on the agricultural systems are of the great concern to the developing countries like Pakistan as economy of Pakistan is dependent of agriculture, very low capacity to adapt and little support from the government. Agroforestry systems offer a win-win scenario as they act sinks for atmospheric carbon at the same time help attaining food security especially to small farmers, enhance farm income, improve soil fertility and offer better environmental conditions.

An assessment based on in-depth knowledge and scientific data is necessary for a realistic assessment of the complex associations and interactions of this vast natural resource base and allied socioeconomic and environmental benefits. To study these very complex agroforestry systems thorough collecting data of complete rotations involving all components of the system is needed. Member states must support long-term reaearch because much of the current knowledge is based upon incomplete data. In addition to an in depth understanding of the benefits from the systems and farmer requirements, mainstreaming of agroforestry requires better market linkages must be provided for the goods and services these systems produce.

In Pakistan, the impact of climate change has only been studied on main annual cereal crops and almost nothing has been done on perennial grasses and trees

which are an integral part of the silvopastoral systems. This is a great challenge to planners, policy makers and researchers to long duration of the perennials and difficulties in changing varieties over short periods pose special challenges and more research is required to address the same. A thorough understanding of how well the perennial trees overcome the impacts of climate change is an essential requirement before promoting their use.

A detailed survey of the existing agroforestry systems may be carried out investigate the interaction among component species, classification of the trees used, and then redefinition of the systems in view of soil conditions, climatic conditions and socio-economic limitations. Detailed studies on the competition and complementarity between trees and crops for sunlight, space and soil recycling of nutrients are needed to be explored. Screening of trees for light, heat along with screening of crops which can tolerate and high relative humidity. In future more emphasis should be given on pest and disease control and allelopathy may be studied in detail. Lastly there is a need study the socio-economic constraints and short-term and long-term benefits of farmers may be ensured.

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Chapter 9

Technological advancement in agro-forestry: Strategy for climate smart agriculture technologies in Sri Lanka

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Abstract

Sri Lanka as an island has a total land extent of 6.5 million hectare and a population of about 23 million people. The country has 3 major climatic zones namely Wet, Intermediate and Dry zones. Tree crop based farming systems have been mainly confined to wet and intermediate zones. As a result, most of agro-forestry systems have been evolved in above climatic zones and the agro-forestry systems are four plantations (tea, rubber, coconut and cinnamon), mixed perennial croplands, Kandyan forest gardens and two SALT based land systems (vegetable and tea). Only the alley cropping based seasonal croplands has been confined to the dry zone. The major recent climatic changes in farming systems inclusive of agro-forestry include increases in extreme events in rainfall, temperature and sea water level. The major climate smart agriculture technologies adopted in above agro-forestry systems include minimum land preparation, mulching, water harvesting technologies, contour hedgerows, stress tolerant crops and crop varieties, sea water barriers, organic input based agro-enterprises and the OK technology. Agro-forestry potential as climate smart agriculture, constrains to up scaling agro-forestry and potentials for improvement of agro-forestry technology in Sri Lanka are discussed in this paper. The existing agro-forestry systems particularly in the wet and intermediate zones need inclusion of climate smart technologies in order to face for recent climatic changes at a satisfactory level and technology adoption programs in progress. In contrast, the dry zone needs introduction of new agro-forestry systems and research in progress in this regard. The country has taken necessary steps to strategically promote climate smart technologies in order to satisfactorily face for recent climatic changes and their future developments on existing farming systems and to ensure dietary, economic, social and environmental services of such agro-forestry systems.

Key words: Agro-forestry Systems, Climate Smart Agriculture, Technological Advancement

Introduction

Sri Lanka as an island has a total land extent of 6.5 million hectare and a population of about 23 million people. It has a great diversity in ecology and therefore a natural resource base for growing wide range of crops with contrasting qualities. For example, the ecological qualities such as 46 agro-ecological regions (NRMCC, 2003), 14 soils at great group level (Panabokke, 1996), topographic classes ranging from flat to mountainous (Dimantha, 1992) and 103 natural river basins with surface and sub surface water resources (NARESA, 1991) show the diversity of this resource base. Under the great ecological diversity in the country, three major agricultural sectors namely plantation, export agriculture and food crops have been evolved and consequently many agro-forestry systems have also been established in those agricultural sectors.

The climate of the country could be characterized as tropical and it has been significantly affected by recent changes. As a result, timely changes in technologies in agriculture have been put into action in order to successfully face the recent climatic changes. This paper discusses major agro-forestry systems in the country and their classification, associations and interactions in different components in agro-forestry, features of recent climatic changes in the country, agro-forestry technologies released for general use, recent climate smart technological advancements and strategic approaches in this regards.

Agriculture and climate change

Agriculture

The land in the country has been used for wide range of agricultural and non-agricultural uses as shown in the Table 1. It also shows the land use changes since 1956. The extent of agricultural land has increased from 45% in 1956 to 60% in 2007 while land extent under various forest types has decreased from 44% to 28.8% during the period. The dense and open forest area of the country during this period decreased from 44% to 23%. The sparsely used crop lands, homesteads and paddy occupy the highest land area in the agricultural sector. The homestead lands are the home gardens where many tree crops are grown. The sparsely used croplands are the lands where the agricultural crops are grown but not properly managed and maintained. The sparsely used crop lands have been increased during this period indicating poor management of agricultural lands in the country. Among the plantation crops, the land extents under tea and rubber plantations have been decreased since 1956. It indicates these lands have become sparsely used lands. There is nearly 2% increased of mixed and perennial crop lands and 1% increased in the coconut plantations.

Climate change

By virtue of geographical location of Sri Lanka within tropics between 5°55' to 9°51' North latitude and between 79°42' to 81°53' East longitude, the climate of the country could be characterized as tropical. Rainfall and temperature have been considered widely in the adoption of climate smart technologies in agriculture.

Rainfall

Rainfall in the country has multiple origins. Monsoonal, convectional and expressional rains accounts for a major share of the annual rainfall. The mean annual rainfall varies from under 900 mm in the driest parts to over 5,000 mm in the wettest parts. The driest parts fall in the Southeastern and Northwestern corners of the country while the wettest parts fall in the western slopes of the central highlands. There is very unique temporal distribution of rainfall over the year which makes four unique climatic seasons in the country. The climatic seasons are the first inter monsoon season (March to April), the Southwest monsoon season (May to September), the second inter monsoon season (October to November) and Northeast monsoon season (December to February).

Temperature

Regional differences observed in air temperature over Sri Lanka are mainly governed by the altitude. The mean monthly temperatures differ slightly depending on the seasonal movement of the sun with some modified influence caused by rainfall. The mean annual temperature in Sri Lanka remains largely homogeneous in the low lands and rapidly decreases towards the highlands. In the low lands, up to an altitude of 100 to 150 m, the mean annual temperature varies between 26.5°C to 28.5°C with an annual mean temperature of 27.5°C. In the central highlands, the temperature falls quickly as the altitude increases. The mean annual temperature of Nuwara Eliya, a city located at an altitude of 1800 m, is 15.9°C. The coldest month with respect to mean monthly temperature in the island is generally January, and the warmest months are April and August.

Table 1. Land use types and extents in Sri Lanka

Main land use type	Sub land use type	Land extent			
		1956		2007	
		000' ha	%	000' ha	%
Agricultural lands	Homesteads	586.3	9.0	1,028.6	15.7
	Tea	257.5	4.0	189.8	2.9
	Rubber	227.4	3.5	183.2	2.8
	Coconut	250.5	3.8	313.7	4.8
	Mixed perennial crops	90.0	1.4	164.3	2.5
	Paddy	510.7	7.8	844.0	12.9
	Sugarcane	0.3	0.0	13.8	0.2
	Sparsely used crop lands	1,008.1	15.4	1,439.5	22.0
	Other crop lands	4.3	0.1	76.8	1.2
Forest lands	Dense forest	1,656.8	25.2	1,123.7	17.1
	Open forest	1,222.6	18.6	404.0	6.2
	Forest plantations	20.6	0.3	86.9	1.3
	Scrubs	100.9	1.5	138.6	2.1
	Grasslands	324.9	4.9	90.6	1.4
	Mangroves/marsh	32.8	0.5	43.5	0.7
Other	Urban and barren lands etc.	267.3	4.1	420.0	6.4
Total		6,561.0	100.0	6,561.0	100.0

Source: Adapted from Land Use Policy Planning Department, Ministry of Lands and land Development, Sri Lanka.

Agro-climatic regions

Depending on the total annual rainfall, the island has been divided into 3 major climatic zones namely Wet, Intermediate and Dry zones (Panabokke, 1996). The Wet zone is the area which receives mean annual rainfall of above 2,500 mm. The Intermediate zone receives mean annual rainfall of 1,750 to 2,500 mm. The mean annual rainfall of the Dry zone is below 1,750 mm. The temporal variation of the

rainfall over the island is very prominent so that two distinct rainfall patterns are evident. In most parts of the country, the rainfall within the year shows a bimodal pattern while in the rest of the area uni-modal distribution pattern is evident. The bimodal distribution pattern shows two rainy periods and two dry periods within the year. One dry period falls during February to March while the other falls during July to September. Based on the three major climatic zones (to represent rainfall) discussed above and three elevations (to represent the temperature) classes namely, low country (< 300 m), mid country (300 – 900 m) and up country (> 900 m), 7 agro climatic zones have been delineated in the country. They are Dry zone Low country (DL), Wet zone Low country (WL), Intermediate zone Low country (IL), Wet zone Mid country (WM), Wet zone Up country (WU), Intermediate zone Mid country (IM) and Intermediate zone Up country (IU). These 7 agro climatic zones have been further delineated into 46 agro-ecological regions (NRMC, 2003).

Recent Climate change

Increases in extreme events of rainfall, temperature and sea water level are some of most significant effects of recent climatic changes.

a). Increases in extreme events of rainfall

In most locations in Sri Lanka, annual rainfall has shown neither significant increasing nor decreasing trend in the face of recent climatic changes in the country. However, variability of annual and seasonal rainfall has increased during recent decades especially with respect to Northeast monsoon which is the source of water for the major cultivation season (Maha) in the country. It is also true for the first inter monsoon rains in the country, especially during April which is the major rain producing month of the minor cultivation season (Yala) in the dry and intermediate zones of the country. Increased occurrence of extremely rainfall events due to recent climatic changes has resulted frequent droughts and floods. Under such a situation, crop losses due to soil moisture stresses (decreased soil moisture) increased soil erosion and damages from storm water are some of adverse effects on farming systems inclusive of agro-forestry systems in the country. Adoption of technologies related to rainwater harvesting, safe use of harvested water during dry spells, arresting soil erosion and minimizing damages from storm water have been identified as climate smart technologies. Fruit bearing seasons of countries major tree crops (fruits and spices) in agro-forestry systems in the dry and intermediate zones are also likely to be affected due to irregularities in rain fall pattern under a changing climate. For example, Rambutan trees in the wet zone agro-forestry systems require 3 to 4 weeks of dry spell in around February in the year for flower development and primordial initiation, to provide a harvest in June. However, sudden occurrence of rains in February deprives that prerequisite, resulting in no flowering in March. Such a

situation has become a common feature in the climate of wet zone during recent past years.

b). Increases in temperature

Being a tropical island with uniformly high temperature regime, most of seasonal crops in farming systems inclusive of agro-forestry systems in Sri Lanka operate near maximum of the optimum temperature range of respective crops. Thus crop injuries due to high temperature are inevitable particularly in seasonal crops in agro-forestry systems in the country under increased temperature. Increased temperature, especially that of night time minimum temperature, tends to decrease the sugar translocation in harvestable fruits and increasing the sour taste in fruit crops. It decreases brix value of fruits. Fiber content of harvestable parts of crops is also likely to increase under increased temperature regime and thereby reducing their palatability. Yield of almost all crops grown in agro-forestry systems would also be negatively affected due to increases in insect damages and infestation of various pathogens such as bacteria, virus and fungi. Increased temperature particularly in dry and intermediate zones of the country accelerates soil organic matter decomposition and thereby lowering soil health.

c). Increases in sea water level

As an island, Sri Lanka is highly vulnerable to increases in sea water level with varying degrees of sectoral impacts. It is highly probable that sea water intrusion to agricultural lands is vulnerable as a result of the changing climate which will lead to further reduction of land available for agriculture. Increased sea water level will also exacerbate coastal erosion in affecting coconut, low country tea and cinnamon plantations in the country.

Agro-forestry systems

Nine major agro-forestry systems have been identified in Sri Lanka (Table 2). Most of such agro-forestry systems have been confined to Wet and Intermediate zones. Greater total annual rainfall (above 2,500 mm in the Wet zone and 1,750 to 2,500 mm in the Intermediate zone) and better distribution of rainfall in the year in the wet and Intermediate zones support for occurrence of wide range of tree species and thereby emerging many agro-forestry systems in the above climatic zones. Only one agro-forestry system, alley cropping based seasonal croplands, has been emerged in the Dry zone which is still at early stages of development.

Tea plantations: Tea (*Camellia sinensis*) has occupied a land extent of 189,800 ha as plantations and small holdings (LUPPD, 2007) and provides black tea for income from export and local consumption. This agro-forestry system has been confined to low, mid and up country in the wet and intermediate zones in the country. In addition to tea, some shade trees such as *Grevillea robusta* (Silver Oak), *Albizia moluccana*, *Acacia decurrens* (Black wattle), *Erythrina lithosperma*

(dadap), *Gliricidia maculata* are grown in this agro-forestry system (Kathiravetpillai, 1990). The shade trees additionally provide green manure, soil moisture conservation, minimizing sun scorch in pruned branches of tea, windbreaks, fire wood and timber.

Rubber plantations: Rubber (*Hevea brasiliensis*) has occupied a land extent of 183,200 ha as plantations and small holdings (LUPPD, 2007). This agro-forestry system has been confined to mid and low country wet and intermediate zones in the country. Research is in progress to introduce rubber in dry zone areas in the country. Rubber has almost all attributes of a forestry species. In most cases, it is grown as a mono crop but in some older plantations, it is intercrop with some other tree crops such as cocoa. Space in between trees is occupied by an undergrowth or live mulch which is in most cases *Pueraria phaseoloides*, *Mucuna bracteata* or grasses. Rubber plantations not only provide a canopy which reduces the impact of sun as well as the atmospheric warming but they root deeper and therefore remove less amount of soil water per unit land area (Samarappuli, 2010). Hence, commercially grown rubber plantations can be considered as an alternative to a forest system, which is sustainable, conveniently renewable and compatible with nature and that provide economic benefits.

Coconut plantations: The coconut (*Cocos nucifera*) has occupied a land extent of 313,700 ha as plantations and small holdings (LUPPD, 2007) and provides various products such as nut, oil and timber for income from export and local consumption. This agro-forestry system has been confined to low country wet and intermediate zones in the country. However, with the expansion of land irrigation systems for agriculture in the dry zone, small holdings with coconut have been significantly expanded to this climatic zone in the country. The majority of coconut plantations, particularly small holdings, have been maintained as monocultures. This inefficient land use system generates low economic returns to the grower. Coconut based agro-forestry (inter cropping, mixed cropping, multiple cropping, alley cropping and mixed farming) research were undertaken for optimum utilization of resources, thereby increasing the productivity and returns from the land. In case of mixed cropping, Gunathilake and Liyanage (1995) reported that cocoa (*Theobroma cacao*), coffee (*Coffea canephora*), pepper (*Piper nigrum*), cinnamon (*Cinnamomum verum*), clove (*Eugenia caryophyllus*), nutmeg (*Myristica fragrans*), ranbutan (*Nephelium lappaceum*), mulberry (*Morus alba morus*), lemonine (*Citrus spp*) and vanilla (*Vanilla planifolia*) performed better in the wet zone in the country and cashew (*Anacardium occidentale*), mango (*Mangifera indica*) and lime (*Citrus acida*) in the intermediate zone.

Table 2. Major agro-forestry (Agro-Silvicultural) systems in the country

Agro-forestry system	Occurrence in climatic zones		
	Wet	Intermediate	Dry
Tea plantation	x	x	
Rubber plantation	x	x	
Coconut plantation	x	x	
Cinnamon plantation	x		
Mixed perennial croplands	x	x	
Kandyan forest gardens	x	x	
SALT based tea lands	x	x	
SALT based vegetable lands	x	x	
Alley cropping based seasonal croplands		x	x
Total	08	07	01

Cinnamon plantations

Cinnamon (*Cinnamomum zeylanicum*) is of great economic and social importance as a spice crop. Sri Lanka is the world largest producer and exporter of “true cinnamon” contributing more than 90 % of the share to the world’s true cinnamon trade. In 2011, the extent of this crop in Sri Lanka was 30,523 ha with an export volume of 13515.t t of quills, 231.2 t of leaf oil and 30.1 t bark, valued at Sri Lankan Rupees million 14228.2 (DEA, 2012).This agro-forestry system has been confined to low country wet zone in the country and it exists as plantations and small holdings.

Mixed perennial croplands

The mixed perennials have occupied a land extent of 164,325 ha (LUPPD, 2007) and provides spices and beverages for income from export and local consumption. This agro-forestry system has been confined to low and mid country wet and intermediate zones in the country. The main crops of mixed perennial croplands include pepper (*Piper nigrum*), coffee (*Coffea sp.*), cocoa (*Theobroma cacao*), clove (*Eugenia carophyllata*) and nutmeg (*Myristica fragrans*) and the space between trees is occupied by grasses as an undergrowth or live mulch. In addition, leaf litter will also serves as dead mulch.

Kandyan forest gardens

The Kandyan forest gardens (KFGs) have been a dominant form of traditional agro-forestry system for centuries, particularly in mid country wet zone in the country. The homesteads in Sri Lanka have occupied a land extent of 1,028,600 (LUPPD, 2007) of which a major portion exists as KFGs. It provides spices, fruits, beverages, condiments, vegetable, flowers, medicinal herbs, fire wood, timber for food and income as well as cool and pleasant living environment for rural communities in the region. On an average, the KFGs are one-third of a hectare in size with over 250 individual woody perennials of about 30 species (NARESA, 1991). Studies related to hydrology (Gunawardena et al., 1994), soil fertility (Kendaragama and Jayasundara, 2012), cash crops (Jacob and Alies, 1987), household income (Kendaragama, 1983), shared gender leadership (Kendaragama and Pathirana, 2011) and alternatives for the system (Gunaratne, 2001) have highlighted some physical, biological, economic and social aspects of this agro-forestry system. Major tree species in this agro-forestry system include coconut (*Cocos nucifera*), king coconut (*Cocos sp.*), areca nut (*Areca catechu*), pepper (*Piper nigrum*), coffee (*Coffea sp.*), cocoa (*Theobroma cacao*), clove (*Eugenia carophyllata*), nutmeg (*Myristica fragrans*), jak fruit (*Artocarpus integrifolia*), Breadfruit (*Artocarpus altilis*), banana (*Musa sapientum*), mango (*Mangifera indica*), dhurian, avocado (*Persea Americana*) and papaw (*Carica papaya*). The space between trees is occupied by grasses as an undergrowth or live mulch. In addition, the leaf litter serves as dead mulch.

Sloping agricultural land technology (SALT) based tea lands

Tea plantations have been a dominant form of agro-forestry on rain-fed uplands in the wet and intermediate zones in the country. Soil erosion has been a major land degradation issue in tea plantations particularly on hilly terrain and the conventional soil conservation has been mainly confined to engineering (mainly stone bunds and lock and spill drains) and agronomic measures. High cost involved in the establishment of engineering methods and some practical difficulties in the adoption of agronomic measures and no recycling of soil nutrients by both of above methods prompted to introduce SALT for tea lands as an alternative soil management technique and investigations on SALT in tea were initiated in 1992 (Ekanayake, 2003). Hence at present, SALT based tea lands have been confined to rain-fed uplands in hilly terrain in the wet and intermediate zones in the country as a sub agro-forestry system evolved from tea plantations.

Sloping agricultural land technology (SALT) based vegetable lands

Vegetable farming has been a dominant form of crop cultivation on rain-fed uplands in hilly terrain in middle elevations in the wet and intermediate zones in the country. Soil erosion by water has been the significant cause for degradation

of such lands due to sloping nature of terrain, experiencing erosive rains, soil disturbances during land preparation prior to crop establishment and some erosion inducing inter cultivation practices. Hence, Sloping agricultural land technology (SALT) has been promoted as an agro-forestry system during the past 3 decades to address the soil erosion issue.

Alley cropping based seasonal croplands

The shifting farming with seasonal crops has been the dominant form of seasonal crop cultivation on rain-fed uplands in the dry zone in the country. The seasonal crops include cereals (maize and finger millets), grain legumes (green gram, black gram and cowpea), oil crops (ground nut, soya beans and sesame), condiments (chilli and onion), country vegetable (cucumber, pumpkin, brinjal, bitter guard and luffa) and fruits (sweet melon). Since few decades back, it has been restricted by population pressure on lands and as a result non availability of adequate lands to continue shifting nature of this farming. As a result, farmers used to continue seasonal crop cultivation on the same land with the use of chemical fertilizers. It has resulted land degradation due to loss of soil fertility and infestation of the land by weeds. Considerable research has been undertaken during the past 3 decades to promote alley cropping as an agro-forestry system on such rain-fed uplands. Research areas include soil fertility aspects (Handawela and Kendaragama, 1991; Seneviratne, et al., 1992; Seneviratne Banda and Kendaragama, 1997), system biomass production (Kendaragama and handawela, 1994), micro biological aspects (Rajapaksha, et al., 1993) and root studies (Seneviratne, et al., 1993). However, this technology has not been taken up by the majority of farmers due to lack of any economic return by the tree component in the agro forestry system. Keerthisena (1995) reported the lack of studies related to economic aspects and adaptability of alley cropping in farming lands. Hence, research is in progress to include trees with economic value for farmers to the hedgerow component of the agro forestry system. In addition, an increase in temperature in the dry zone area has been observed as a result of recent climatic changes. It has resulted making cultivation of some crops such as tomato impossible in selected areas in the dry zone. The alley cropping technology is capable of controlling increases in temperature under simulated forest condition by hedgerow tree canopy and therefore, research is in progress to reintroduce this technology as a mitigation measures for increases in temperature during crop growing period.

Associations and interactions in agro-forestry

Tree crop association

Significant tree crop association exists in most of agro-forestry systems in Sri Lanka. Trees in above agro-forestry systems include crops and plants providing supporting services. Among the plants providing supporting services, *Gliricidia*

sepium has been grown in alley cropping, SALT in vegetable, mixed perennial crop lands, Kandyan forest gardens, tea plantations and coconut plantations. *Flemingia congesta* and *Calliandra calothyrsus* have been suggested as most suitable for SALT in tea (Ekanayake, 2003). In case of rubber plantations, crop has become the tree species and a creeping plant, *Pueraria phaseoloides* or *Mucuna bracteata* in most cases, has been grown as live mulch.

Purpose of growing trees in association with crops includes obtaining green manure for companion food crops, soil erosion control by placing tree lopping on contours, maintaining simulated forest condition by tree canopy management, soil moisture conservation by placing tree lopping as mulch, feeding domestic animals such as cattle and goat with green biomass of trees and fire wood from hard wood of tree lopping for domestic needs.

Tree crop interactions exist in many agro-forestry systems in the country which include competition for soil moisture, sun light, essential plant nutrients and other growth resources. Development of appropriate technologies for tree canopy management helps minimizing shading effects on companion food crops. Significant competition for available phosphorus has been showed in alley cropping (Handawela and Kendaragama, 1991; Seneviratne Banda et al., 1992) and Kandyan forest garden systems (Kendaragama and Jayasundara, 2012) in the country. Adoption of soil test based fertilizer use and promotion of organic manure use have been practiced to minimize tree crop competition for essential plant nutrients and other growth resources. Adoption of water harvesting technologies such as lock and spill drains, water percolation pits and farm ponds helps minimizing tree crop competition for soil moisture. Further, lopping tree canopy during dry periods also mitigates competition for soil moisture. Chandrapala et. al. (2004) showed that hedgerow intercropping in sloping lands in central highlands in the country exerted significant competition against the annual crop for growth resources but combining appropriate agronomic soil conservation measures such as contour furrowing and mulching with hedgerow intercropping could minimize above adverse effects.

Interaction with other farm component

Agro-forestry systems provide green biomass and it is used as fodder for feeding farm animals in establishing tree-crop-animal integration in farms. Similarly, agro-forestry systems also provides hard wood and it has many uses such as source of energy for cooking and materials for construction of on farm soil conservation structures like brush wood and hard wood check dams. Agro-forestry also serves as wind breaks for other farm components and bio structures

for drainage improvement in low lying areas. Handawala (1989) suggested alley cropping as an alternative for shifting cultivation which permits continuous farming in avoiding land wastage due to long term fallowing.

Agro-forestry-environment linkages

Environmental linkages from agro-forestry systems, alley cropping in particular, in the country include soil erosion control, soil moisture conservation, in-situ generation of organic matter for maintenance of soil organic matter (Kendaragama and Handawela, 1994) and nutrient recycling, potassium in particular (Kendaragama, 1995). Dharmasena (1992) showed the significance in the use of *Gliricidia sepium* for erosion control in rain-fed uplands of the dry zone in Sri Lanka and the use of grass hedges (Dharmasena, 1996) have also been effective in soil erosion in the same environment.

Agro-forestry-farming system linkages

Some of the benefits of practicing agro-forestry, alley cropping in particular, include suppression of grass type weeds in cultivation plots (Kendaragama, 1995), improvements in soil tilth, improvements in soil microbial populations (Rajapaksha et al., 1993), improvement in soil physical and chemical properties (Handawela and Kendaragama, 1991; Gunasena et. al., 1991) and creation of comfort micro climate for farm workers. Improvements in soil tilth help land preparation and post plant weed control by hoe easier in crop management. Improvement in overall soil fertility showed higher yields in companion food crops such as maize particularly in alley cropping systems. Yield improvements in companion food crops due to integration of tree legumes have been reported by many case studies (Gunasena, 1989; Handawala and Kendaragama, 1991; Chandrapala et. al., 2004). As discussed above, this yield improvement could mainly be attributed to supply of nitrogen from legume tree biomass, recycling of potassium and other bases by trees, improvement of soil physical and micro biological properties, soil conservation by contour hedgerows and suppression of weeds under simulated forest conditions.

Agro-forestry technologies

As discussed in the section 2 in this paper, nine agricultural systems have been identified as major agro-forestry systems in Sri Lanka which include four plantations (tea, rubber, coconut, and cinnamon, mixed perennial croplands, Kandyan forest gardens, SALT based Tea lands, SALT based vegetable lands and alley cropping based seasonal croplands. Technological advancements in above agro-forestry systems related to climate smart agriculture are discussed below.

Minimum land preparation

Minimum land preparation has been practiced for crop cultivation in most of agro-forestry systems in Sri Lanka as an energy smart technology. It helps maintaining soil carbon stocks and thereby contributing towards mitigating climate change effects. Major land preparation types in major agro-forestry systems in the country are summarized in the table 3. Seasonal land preparation has been limited to only two forestry systems namely SALT based tea and vegetable lands and alley cropping based seasonal croplands. In the other forestry systems, land preparation with significant soil disturbances has been limited to initial establishment of tree crops. Therefore, soil disturbance is minimal in most of agro-forestry systems compared to other conventional farming systems in the country.

Mulching

Practice of mulching has been a common technology to all agro-forestry systems in Sri Lanka as nutrient smart technology (table 4). The mulching materials include fallen tree leaves as dead mulch, creeping types legumes such as *Mucuna* species, rice straw brought from paddy fields, live mulch with grasses and lopped tree hedgerow biomass. Satisfactory adoption of mulching technology is confined only to agro-forestry systems in the country. Practice of mulching mitigates land degradation due to crusting and sealing, helps maintaining soil organic matter, improves soil physical properties and supplies essential plant nutrients to surface soil. Further practice of mulching helps mitigate the adverse effects of increased temperature which is a resultant of recent climatic changes in the country.

Water harvesting technologies

Considerable fraction of rain water exists as runoff in exploited lands due loss of organic matter, crust formation and sealing pores in surface soil. This runoff water generation particularly after heavy rains creates some environmental issues such as acceleration of soil erosion, formation of gullies, splash floods and damaging irrigation structures in farming lands. Increases in extreme events in rainfall due to recent climatic changes have aggravated the problem. Some of the promising runoff water harvesting technologies developed in the country includes lock and spill drains, water percolation pits and farm ponds. These technologies have not been recommended for lands having a threat of occurring landslides, earth slips and other forms of mass movements in soil.

Table 3. Land preparation practices in agro-forestry systems in Sri Lanka

Agro-forestry system	Land preparation practices
Tea plantation	Initial land preparation by hoe and thereby periodic weed control by light tools.
Rubber plantation	Initial land preparation and periodic weed control on common flat forms.
Coconut plantation	Initial land preparation limited to planting pits.
Cinnamon plantation	Initial land preparation limited to planting pits and thereby weed control by hoe.
Mixed perennial croplands	Initial land preparation limited to planting pits.
Kandyan forest gardens	Initial land preparation limited to planting pits.
SALT based tea lands	Initial land preparation by hoe and thereby periodic weed control by light tools.
SALT based vegetable lands	Seasonal land preparation by hoe for establishment of seasonal crops, weed control by hoe and earth up for selected crops such as potato
Alley cropping based seasonal croplands	Seasonal land preparation by hoe for establishment of seasonal crops and weed control by hoe.

Lock and spill drains

The Lock and spill drains have been developed for lands having even surfaces and a considerable soil depth. This technology has been well taken by some plantations (tea, coconut, and cinnamon), mixed perennial croplands and Kandyan forest gardens. This structure is established on contour on the land with between row spacing ranging from 4.5 to 8 m depending on land slope. The width and the depth of the drain are 60 cm and 45 cm, respectively. In the drain, after every 4 to 5 m length, soil in a length of 45 cm kept unexcavated to form a lock component in order to control horizontal movement of runoff water in the drain and to facilitate water entry into soil.

Table 4. Mulching being practiced in agro-forestry systems in Sri Lanka

Agro-forestry system	Type of mulching being used
Tea plantation	Fallen tea leaves as dead mulch
Rubber plantation	Live mulch with <i>Mucuna</i> species, fallen rubber leaves as dead mulch and rice straw brought from paddy fields to young plantations
Coconut plantation	Live mulch with grasses and fallen coconut leaves as dead mulch placed at the base of coconut plants
Cinnamon plantation	Fallen cinnamon leaves as dead mulch
Mixed perennial croplands	Live mulch with grasses and fallen tree leaves as dead mulch
Kandyan forest gardens	Fallen tree crop leaves as dead mulch
SALT based tea lands	Lopped hedgerow tree biomass and crop residues
SALT based vegetable lands	Lopped hedgerow tree biomass and crop residues
Alley cropping based seasonal crop lands	Lopped hedgerow tree biomass and crop residues

Water percolation pits

Water percolation pits have been developed for lands having uneven surfaces and a considerable soil depth. This technology has been well taken by Kandyan forest gardens and mixed perennial croplands. The water percolation pits can be installed in main drains and leader drains. It can also be placed in the cultivated land also in areas where considerable floor of runoff water is generated after rains. Percolation pit volume depends on the volume of runoff water generated in the land. Vertical surfaces of the pit can be insulated with loose rock, used tyre or any other suitable material.

Farm ponds

The farm ponds have been developed for lands having considerable soil depth and natural surface depressions. Volume of the pond depends on the volume of water to be harvested. Harvested water can be used for irrigating crops and other farm activities. Surface area occupied by the structure varies from 30 to 500 m² and the inner surface of the pond is usually insulated by mud, polythene or any other suitable material.

Contour tree hedgerows

Contour hedgerow technology is usually adopted in the form of double hedgerow in SALT and single hedgerow in alley cropping. Trees on contours help not only controlling soil erosion but also improving soil fertility. Hence, these technologies are more suitable for lands degraded by both soil erosion and declining soil fertility.

Sloping agricultural land technology (SALT) in tea

The SALT in the form of double tree hedgerow has been mainly adopted in tea lands in central highlands of Sri Lanka. Ekanayake (2003) reported a research review on management of tea lands through SALT and showed that *Flemigia congesta* and *Calliandra calothyrsus* are the most suitable species for hedgerows in tea and the optimum spacing was 7 to 8 m between hedgerows. The best time to establish hedgerows was when planting rehabilitation grass or tea and there was evidence to indicate improvements to soil chemical properties, growth and yield of tea.

Sloping agricultural land technology (SALT) in vegetable

The SALT in the form of double tree hedgerows has been mainly adopted in vegetable lands in central highlands of Sri Lanka. In vegetable, the *Gliricidia* plant has been used as the tree legume. A width of 45 cm is maintained in between hedgerows and a distance of 15 cm within trees in a hedgerow. The spacing between adjacent double hedgerows depends on land slope and it ranges from 4.5 to 18 m. Hedgerow tree lopping, weeds collected from cultivated area and crop residues are placed in between tree hedgerows in order to arrest soil loss due to erosion.

Alley cropping

Alley cropping in the form of single tree hedgerow has been mainly adopted in rain-fed uplands in the dry and intermediate zones in the country. The *Gliricidia* plant has been used as the tree legume. A distance of 100 cm is maintained within trees in a hedgerow and the spacing between adjacent single hedgerows is 5 m. Hedgerow tree lopping, weeds collected from cultivated area and crop residues are placed as a mulch on cultivated area in order to arrest soil erosion, minimize soil moisture losses and to reduce surface soil temperature. This technology was introduced in early 1980s but the diffusion of the technology was not at a satisfactory level mainly due to the fact that the tree component does not give any economic benefit to farmers. Research attention has been paid again to reintroduce this technology as a mitigation measure for increases in soil and

ambient temperature under recent climatic changes because this technology creates simulated shading for companion seasonal food crops.

Multifunctional contour bunds

Soil bunds have been recommended for soil and water conservation in low country dry and intermediate zones in the country. However, farmers are reluctant to adopt this technology because at the time of first plowing in land preparation, the bunds are not visible and covered by off season vegetation. It makes land plowing very difficult in avoiding damages to soil bunds. As a solution to this practical problem, multi-functional contour bunds were developed and are being tested on farmer field for its adoptability and accessibility. In this technology, soil bunds are established in the land with wider spacing of about 30 to 40 meter apart and different types of trees useful to the farmer are established on the bund. In addition to soil and water conservation from soil bund, trees provide multifunctional economic benefits to the farmer. Some of the trees preferred by farmers for establishment on soil bunds include miti murunga (*Moringa oleifera*), kathurumurunga (*Sesbania grandiflora*), lime (*Citrus aurantifolia*) and pomegranate (*Punica granatum*). Research is in progress to integrate suitable shrub species with above tree species in order to enhance economic returns from above multifunctional contour bunds.

Stress tolerant crops and crop varieties

Expansion of extents in saline and sodic soils in farming systems, occurrence of frequent droughts and subsequent floods, sea water intrusion and raising temperature have been identified some adverse effects of farming lands related to recent climatic changes. Crop and variety screening programs are in progress in the country in order to release crops and varieties tolerant to above stress situations. In addition, water barriers have been adopted to control sea water intrusion into some farming systems in the coastal are in the Southwestern region.

Organic input based agro-enterprises

Organic input use in place of chemical fertilizer and pesticides has been an emerging strategy for ensuring quality of crop harvest and thereby obtaining better prices for crop produce in many recently evolved agro-enterprises in the country. Such enterprises have also been diffused to many agro-forestry systems such as plantations (tea, coconut and cinnamon), Kandyan forest gardens and mixed perennial crop lands. This kind of enterprises encourage organic material addition to farm lands, indirectly helps maintaining soil carbon stocks and reducing carbon release to the atmosphere.

OK technology

Vegetable cultivation in Kandian forest gardens has been diminished in past 4 decades due to severe damages from small wild animals such as wild boar, porcupine and rabbit. Interaction between trees and herbs like vegetable for water, sun light and other growth resources aggravated the above problem. Hence, a technology called “OK technology” has been developed in 2007 and promoted since then in order to enhance vegetable production in the forest garden system. The OK (Over Knee) technology means cultivation of herbaceous vegetable using a soil based growth media placed in individual pots and mounted on a steel structure. This technology has been accepted by the forest garden communities but the diffusion of the technology within the garden system has been restricted by the high cost involved (US \$ 75) in the construction of the metal structure of the technology. It suggests the need of a financial concession at the early stages in the promotion of this technology.



Figure 1. Metal structure developed for OK technology and vegetable grown on the structure

Agro-forestry potential as CSA technology

Almost all agro-forestry systems in the country have potentials as climate smart agriculture technologies.

- The tree component has an ability develop simulated forest condition in the crop growing environment and thereby controlling increases in ambient temperature particularly during day time.

- Continuous addition of organic matter in the form of tree lopping, weed biomass, crop residues, live mulch, dead mulch and leaf litter to soil helps maintaining soil organic matter status.
- Practice of no tillage or minimum tillage in crop cultivation helps maintaining carbon stocks in soil in reducing carbon emission to the atmosphere.

Hence, agro-forestry can be considered potential systems for climate smart agriculture.

Constraints to up scaling agro-forestry

Constraints to up scaling agro-forestry sector in Sri Lanka exist in many directions and some of the considerable constraints are discussed below.

- At present in Sri Lanka, many government institutions are involved in agro-forestry sector. The institutions include Department of Agriculture, Provincial Department of Agriculture, Department of Export Agriculture, Department of Animal Production and Health, Tea Research Institute, Rubber Research Institute, Coconut Research Institute, Forest Department, Mahaweli Authority of Sri Lanka, Hadabima Authority of Sri Lanka, Land Use Policy Planning Department and Agricultural Universities. Many private sector organizations and non government organizations are also involved particularly in expansion of agro-forestry sector in the country. Therefore, an institutional integration is needed to improve agro-forestry sector. Further, it is suggested to develop a master plan for agro-forestry sector.
- Strengthening gap filling research, training on new technologies and adoption of effective extension methodologies related to agro-forestry has a significant potential for scaling up of this technology.
- In many agro-forestry systems such as alley cropping, SALT, mixed perennial croplands and coconut plantations, the tree component, *Gliricidia sepium* in most cases, does not provide any significant economic returns for farmers. It has restricted the expansion of such agro-forestry systems among farming communities. Research is needed to find out tree species which provides economic returns also for farmers in addition to other services to the particular agro-forestry system.
- *Gliricidia sepium* has been used as the tree component in many agro-forestry systems such as alley cropping, SALT in vegetable, mixed perennial crop lands, Kandyan forest gardens and tea plantations. The vegetative growth of *Gliricidia sepium* exists at an inadequate level at higher elevations particularly above 300 meter above sea level.

Potentials for improvement

Potentials for improvement of agro-forestry sector in Sri Lanka exists in many directions and some of the significant potentials are discussed below.

- Some sub sectors in agro-forestry have not been fully exploited in Sri Lanka. The sub sectors include silvi-pasture, silvo-fishery and other potentials such as application of agro forestry technology in water management, salinity management and land reclamation. Above sub sectors needs fully exploitation in Sri Lankan agriculture.
- Acceleration of processes such as deforestation, degradation exploited lands, loss of bio diversity and climate change has been significant environmental issue in Sri Lanka. Expansion of agro-forestry helps mitigate or reverse above processes.

Conclusions

Sri Lanka has 3 major climatic zones namely Wet, Intermediate and Dry zones. Tree crop based farming systems have been mainly confined to wet and intermediate zones in the country due to adequate distribution of rainfall in the year. As a result, most of agro-forestry systems have also been evolved in above climatic zones and the systems include major 4 plantation systems (tea, rubber, coconut and cinnamon), mixed perennial croplands, Kandyan forest gardens and SALT based tea and vegetable lands and alley cropping based seasonal croplands.

The climate smart agriculture technologies adopted in above agro-forestry systems include minimum land preparation, mulching, water harvesting technologies, contour hedgerows (SALT and alley cropping and multi-functional contour bunds), stress tolerant crops and crop varieties, sea water barriers, organic input based agro-enterprises and the OK technology.

The potentials of agro-forestry systems for promotion of climate smart agriculture include development of simulated forest conditions for companion crops; continuous addition of organic materials to soil in the form of leaf litter, tree lopping, weed biomass and crop residues; and practice of no tillage or minimum tillage.

Lack in institutional integration; strengthening gap filling research, training on new technologies and adoption of effective extension methodologies; significant economic returns from most of tree species being used in agro-forestry systems in the country; and suitable tree species for higher elevations in the country have been major constraints for promotion of agro-forestry in the country.

Some sub sectors in agro-forestry which have not been fully exploited in country can be considered as potentials for improving agro-forestry sector in Sri Lanka. The country has taken necessary steps to promote above climate smart

technologies in order to satisfactorily face for recent climatic changes and their future developments on existing farming systems and to ensure dietary, economic, social and environmental services of such farming systems.

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Chapter 10

Challenges and Way Forward

The SAARC Regional Consultation meeting on “Technological advancement in agroforestry systems: strategy for climate smart agriculture technologies in SAARC Countries” was held during 16-18th June 2015 in ICAR - Central Agroforestry Research Institute (CAFRI), Jhansi, Uttar Pradesh. Following the country presentation a working group session was organized to discuss and identify issues and way forward.

Issues

- Absence of policy specific on Agroforestry in many Member States
- Limited awareness about agroforestry
- Shortage of extension personals in the field of agroforestry
- Unorganized structure of agroforestry institutions and agriculture departments
- Poor technology dissemination and adoption
- Need for network on SAARC Agroforestry for technology dissemination

Way Forward

1. Policy

- Formulation of Agroforestry Policy/Framework/Guidelines for all SAARC countries

2. Research

- Complete inventory of existing AFS in all the SAARC countries (D&D Analysis)
- Identification of suitable climate smart agroforestry practices for different SAARC countries.
- SAARC regional coordinated project on AF in line with AICRP on Agroforestry in India
- Agroforestry intervention for watershed management (water harvesting ,storage, application and management, and participatory watershed management approach)
- Research on fodder species and livestock that can be integrated into agroforestry system
- Energy Smart Agroforestry (Biofuel – Jatropha, Pongamia, Madhuca, Simaruba, and bioenergy- Fuelwood, Gasifiers)

3. Extension and Training

- Training of extension in agroforestry and AF based watershed management
- Technology dissemination through field visits, exhibitions, and on farm trials,
- Organize mass media: radio talks, Kisan call center, leaflets and news papers
- Training on D & D analysis
- Methodology to quantify Ecosystem services
- Training on conservation agriculture with trees, integration of trees and their management in agriculture, and biofuels-bioenergy
- Technology dissemination and adoption of smart and successful agroforestry technologies
- Establish network and website creation like SAAN (South Asia Agroforestry Network)

List of Participants

SAARC Member States

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7. Dr. Ram Newaj, Principal Scientist (Agronomy), CAFRI, Jhansi
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Photos



Dr. SM.Bokhtiar, Director giving Inaugural Remarks



Consultation Meeting in Session



Regional participants visits agroforestry trial sites in CAFRI

